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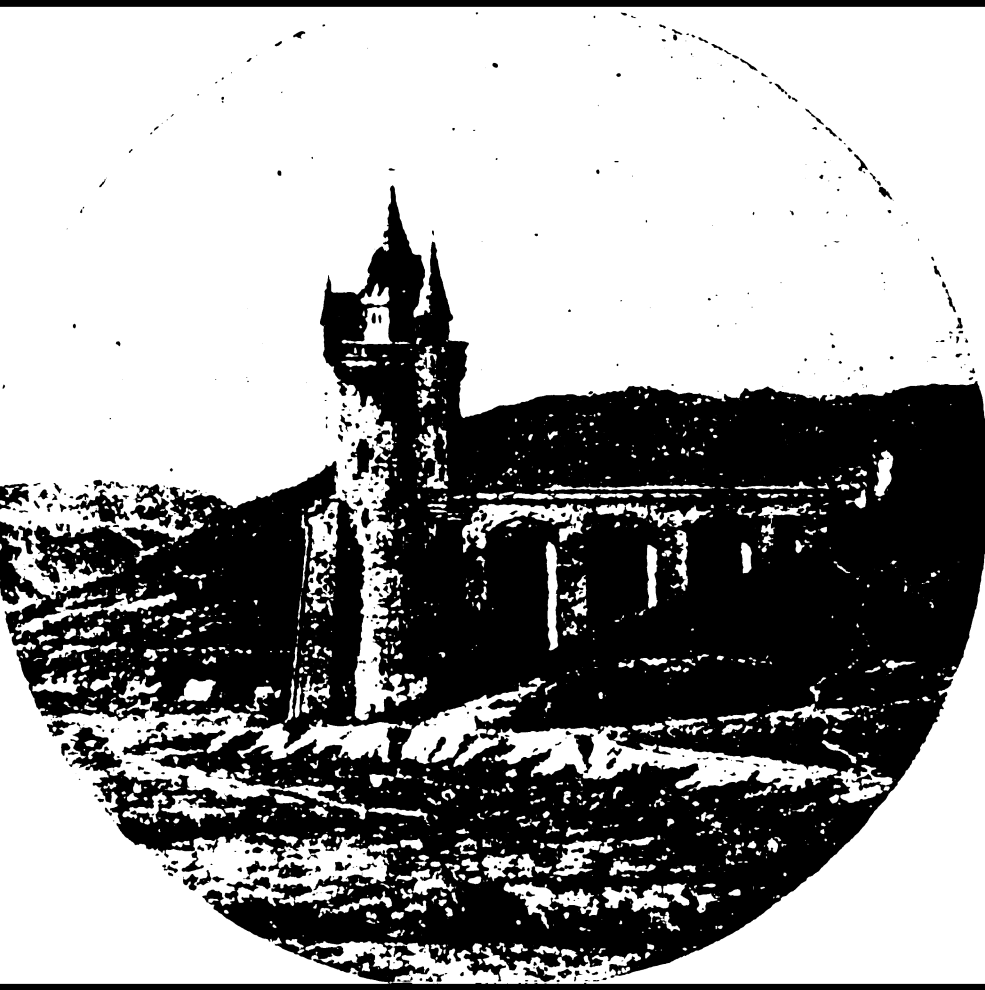

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Institution of Civil Engineers (Great Britain)

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# MINUTES OF PROCEEDINGS

OF

# THE INSTITUTION

OF

# CIVIL ENGINEERS;

WITH OTHER

## SELECTED AND ABSTRACTED PAPERS.

VOL. CXXVI.

1896

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

LONDON:
Published by the Institution,
GREAT GEORGE STREET, WESTMINSTER, S.W.
[TELEGRAMS, "INSTITUTION, LONDON." TELEPHONE, "3051."]
1896.

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THE INSTITUTION OF CIVIL ENGINEERS,
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THE

# INSTITUTION

OF

# CIVIL ENGINEERS.

SESSION 1895-96.—PART IV.

## SECT. I.—MINUTES OF PROCEEDINGS.

14 April, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

*Member.*

JAMES HENRY ANDERSON.
CORNELIUS EDWARD CARDEW.
CHARLES CLAUDE CARPENTER.
EDWARD ELLIS.
ERNEST JAMES RUMSBY.
GEORGE THOMAS SIBBERING.
HERBERT BLOMFIELD SMITH.
FREDERIC JOHN RAMSBOTTOM SUTCLIFFE.

And that the following Candidates had been admitted as

*Students.*

THOMAS CONYNGHAM BRUTTON ANDERSON.
FRANCIS JAMES BROADBENT.
HERBERT JAMES BUDB.
ALFRED DOVER DELAP, B.E.
ALFRED TOMLIN EAST.
HENRY CHARLES DIGBY FEARON.
JAMES HERMANN FIELD.
WALFORD HENRY GALE.
SPENCER OSWALD HEINEMANN.
JOHN HOLLIDAY.
PERCY NICHOLAS HOOPER.
GEORGE PASCOE MAIR.
EDWARD THOMAS EVERY MILLER.
EDWARD ERNEST PEARSON.
ADRIANO SALDANHA.
CHARLES MONTGOMERIE SMYTH.
JOHN HORATIO TRENERRY.
JOHN ATKINSON TUZO.
JOHN HERBERT VEASEY.
LEWIS PHILLIPS WINBY.

The Candidates balloted for and duly elected were: as

*Members.*

EUGENE GRIFFIN.
WILLIAM HENRY LE QUESNE.
JOHN WALKER.

*Associate Members.*

HERBERT JEFCOATE ATKINSON, B.E.
NORRIS GARRETT BELL.
WILLIAM MURRAY BINNY.
ROBERT BLEAZBY, B.E.
ERNEST NEWTON BOWDEN, Stud. Inst. C.E.
EDWARD BOX.
ANDREW BOYD, B.E.



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*Associate Members*—continued.

PATRICK JOSEPH CORBETT, Stud. Inst. C.E.
WILLIAM CRAIG.
GEORGE BELBEN CRESSWELL.
WILLIAM ROBERTSON LIDDERDALE FORREST, Stud. Inst. C.E.
THOMAS GILBERT JONES, B.Sc., Wh.Sc., Stud. Inst. C.E.
ALEXANDER LADE, Stud. Inst. C.E.
CHARLES JULIUS ALFRED MITTELHAUSEN.
HERBERT EDGAR PECK.
FREDERICK SAUNDERSON.
ALEXANDER SMITH.
FREDERICK HENRY SMITH.
MAURICE AMBROSE VILLIERS-STUART, Stud. Inst. C.E.
RICHARD WALTER WALSH.
CYRUS JOHN RICHARD WILLIAMS.
WILLIAM RICHARD WILLIAMS.
ARTHUR WOOD-HILL, Stud. Inst. C.E.
FRANK WORRALL.
ADAM FREDERIC TRAMPE WORSÖE.

*Associates.*

BERTRAM BLOUNT.
EDGAR CHARLES SPILSBURY, *Major R.E.*

---

(*Paper No. 2913.*)

## "The Thirlmere Works for the Water-Supply of Manchester."[1]

By GEORGE HENRY HILL, M. Inst. C.E.

THE city of Manchester and the surrounding districts were, previously to the auxiliary supply being obtained from Thirlmere, wholly supplied with water by gravitation from Longdendale, a valley situated about 18 miles east of the city, down which flows the River Etherow, one of the principal tributaries of the River Mersey. The drainage-area contributing this supply is 19,000 acres, the area of the reservoirs being 855 acres and their storage-capacity about 6,000 million gallons. The quantity of water available, exclusive of that delivered as compensation to the river, is about 25 million gallons per day. The works, including the service-reservoirs, mains and piping, have cost up to the year 1894 about £3,150,000.

In the year 1875 the consumption reached about 17 million gallons per day, having increased from about 8 million gallons per day in 1856. It became evident therefore, in view of the period which must necessarily elapse before any material extension of the supply could be completed, that the time had arrived when the question of providing for the future needs of the city and district must be fully considered. The Corporation, after an

[1] The discussion upon this communication was taken in conjunction with the following one by Mr. Deacon descriptive of the Vyrnwy supply to Liverpool.

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examination of various sources, determined to adopt the scheme for obtaining an additional supply of water from Thirlmere, one of the lakes in the English Lake District, and the Act of Parliament authorizing this scheme was obtained in May 1879. The first contract was let in December 1885, the works being opened and the supply of water to Manchester from Thirlmere commenced on the 13th of October, 1894.

## General Description.

The natural drainage-area of Lake Thirlmere is 7,400 acres; but the scheme includes the water from a further area of 3,600 acres, which will eventually be diverted into the lake. The total drainage-area included in the scheme is therefore 11,000 acres. The geological formation of the drainage-area is Lower Silurian, the rock being very near to the surface. There is scarcely any peat, the water which flows from the drainage-area, even in times of heavy flood, being therefore almost as clear and free from turbidity as in ordinary weather. The mountains surrounding the lake are very precipitous and are used as sheep pastures, the highest point of the watershed being Helvellyn, which is 3,118 feet above the sea, or 2,585 feet above the natural level of the lake.

The rainfall in the Thirlmere district is very large, a portion of the drainage-area being only about 4 miles to the east of Seathwaite in Borrowdale, where observations have shown the rainfall to be one of the highest in Great Britain, amounting in some years to as much as 243 inches. On the Thirlmere watershed it varies in wet years between about 100 inches in the valley and about 137 inches on the hills on the west side of the lake, and in dry years between about 60 inches and about 80 inches at the same places, *Fig. 1.* In 1878, when the Bill was before Parliament, there were no records of the rainfall upon this drainage-area, it therefore had to be estimated by the examination of the returns in other parts of the Lake District. The quantity of water obtainable for the city was, after allowing 5,500,000 gallons per day as compensation water to the river, assumed at about 50 million gallons per day. The average rainfall at Thirlmere for the three dry years 1887, 1888 and 1889, was 71 inches, as compared with 40 inches in the mountain district of Longdendale, the source of the present supply, *Figs. 1* and *2*. From the almost entire absence of peat, and the precipitous and rocky character of the Thirlmere area, the yield is largely in excess of that usually obtainable from drainage-areas in this country.



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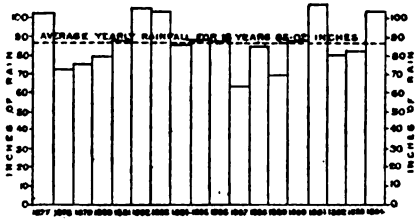
The area of the lake, Fig. 5, Plate 1, in its natural condition, and at its normal level of 533 feet above sea-level, is 328¼ acres. By the Act of 1879, the Corporation is prohibited from abstracting any water from the lake when it is below this level; but powers are given to raise the natural level 50 feet. The area of the lake when so raised will be 793 acres, and the capacity of the raised portion will be 8,130,686,693 gallons, equivalent to a depth of 32⅔ inches on the total drainage-area. The water is conveyed from Thirlmere by an aqueduct (Figs. 3 and 4, Plate 1) having a total length of 95⅞ miles, consisting of tunnelling, cut-and-cover, and cast-iron pipes, which terminates at a new reservoir at Prestwich, 4 miles from Manchester. The aqueduct passes through various geological formations, beginning in the Lower Silurian

*Fig. 1.*



THIRLMERE (AVERAGE OF SIX GAUGES).

*Fig. 2.*

LONGDENDALE (WOODHEAD GAUGE).

and ending near Manchester in the Coal Measures. The whole of the storage is above the level of the aqueduct.

The tunnels and cut-and-cover portions of the aqueduct, about 51 miles in length, together with some of the bridges, valve-houses, and other special works which could not conveniently be enlarged hereafter, have been constructed of the full size ultimately required when the whole quantity of 50 million gallons per day is being drawn from Thirlmere. In the case, however, of the cast-iron pipes, only one of the five lines, each of which is 45 miles in length, has been laid, as the city does not at present require a supplemental supply of more than 10 million gallons per day.

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## Works.

The water of the lake is impounded by a masonry dam, Figs. 12 and 13, Plates 1 and 2, which has been constructed across the outlet at the north end of the lake. The dam is divided into two portions by a small isolated hill, the summit of which rises to about the same level as the top of the dam. The foundation is everywhere sunk into the solid rock, and at the river reaches a maximum depth of 50 feet below the bed. The dam is constructed of concrete gauged 5 parts of broken stone and sand to 1 of cement; large blocks of rock being embedded in it, sufficiently far apart to be properly surrounded with concrete. These blocks were not allowed to be placed within about 7 feet of the inner face. All the fine material for the concrete was produced by grinding the stone of the district. The dam is faced on both sides with heavy chisel-bedded and jointed masonry, of an average thickness of about 2 feet, well bonded into the concrete of the dam. The batter on the lake side is 1½ inch to a foot, and the outside is curved to a radius of 100 feet. The dam is finished at the top of the outer face by two courses of ashlar 18 inches thick, and on the inner face by one course of the same thickness. The top of the dam carries a roadway 16 feet wide.

Surplus water and compensation water are discharged from the lake by pipes laid in a tunnel driven through the isolated hill. The tunnel is 12 feet wide and 9 feet high; the portion on the lake side of the dam is lined with blue bricks in cement, the outer portion being in strong rock is left unlined. The tunnel, which was used for the passage of the water from the lake during the construction of the dam, is closed on the centre-line of the dam by a brickwork stop, through which two cast-iron pipes 3 feet in diameter and one cast-iron pipe 18 inches in diameter are laid. The larger pipes are used for discharging surplus water, and the smaller pipe delivers the compensation water to the gauge-basin.

A shaft, 10 feet in diameter, is sunk on the line of the tunnel a short distance outside the centre-line of the dam, and is lined with blue bricks faced with white glazed bricks. The working arrangements for the valves on the cast-iron pipes are placed in this shaft. Two valves, Figs. 20, Plate 3, are placed tandem on each of the large pipes, one being worked by hydraulic power and the other by hand-gearing. The hydraulic power is obtained through a 6-inch pipe fed from a small tank situated on a stream on the hill-side above the south end of the dam. The tank is so

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arranged as to intercept all sand or earthy material and prevent its passage into the pipe. At the valve-house which covers the shaft, the 6-inch supply-pipe is reduced to a copper pipe 3 inches in diameter made of copper. This pipe is carried down the shaft to a point near the valve at which it is reduced to two $\frac{3}{4}$-inch pipes of the same metal which are connected respectively with each of two hydraulic cylinders, Figs. 17, 18 and 19, Plate 3. The $\frac{3}{4}$-inch pipes which supply the cylinders are each controlled by a four-way cock worked by a lever. For the purpose of raising this lever, a chain is attached to the end of it and passes up to a hand-wheel in the head-stock fixed in the valve-house. To lower the lever, weights hung to it come into operation when the hand-wheel chain is slackened. There is also fixed in the valve-house a graduated indicator connected with each valve, which shows the exact position of the door of that valve.

Each hydraulic cylinder is placed immediately above the valve, the piston being connected by a cross-head to two lifting-rods attached to the door of the valve. The diameter of each cylinder, which is lined with gun-metal, is 30 inches, and a pressure of 40 lbs. per square inch can be applied to them. All rods and working parts are of Delta metal. A valve worked by hand is placed at the bottom of the valve-shaft on the 18-inch pipe. The shaft at the level of the ground is covered by a valve-house in which the headstocks of the valves in the tunnel are fixed, and it is from this building that the waterman controls the discharge of water through the tunnel.

The waste-weir is constructed in solid ground, and is entirely unconnected with the masonry of the dam. The water, after flowing over an ashlar crest, 100 feet in length, is gathered into an artificial swallow-hole, 20 feet deep, from the bottom of which it passes through a tunnel about 25 yards long into the waste-watercourse, and so to the river. The width of the waste-watercourse varies between 12 feet at the end of the tunnel and 40 feet where the fall is less considerable. For the present supplementary supply of Manchester, it is not necessary to retain a greater depth of water in the lake than 20 feet. An overflow and tunnel through which the water may pass has therefore been provided at the 20-foot level, immediately under the overflow already described, communicating with the tunnel and waste-watercourse. This overflow is of course only temporary, and will be closed when it is found necessary to impound a greater depth of water in the lake.

A gauge-basin has been constructed to receive the compensation water delivered by the 18-inch pipe laid through the discharge

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tunnel. The water is discharged into a basin where it is stilled; it then enters a second basin, in the walls of which there are ten orifices exactly alike in all respects. Arrangements are made by which the water from one of these orifices can be discharged into and measured in a test basin. By this means the quantity delivered to the river can at any time be accurately ascertained.

The raising of the lake necessitated the diversion of the main coach-road between Windermere and Keswick for a length of about 2 miles. An entirely new road about 5½ miles long has been constructed on the west side of the lake, and also a new road over the top of the dam, which forms a connection between the roads on the two sides of the valley. In consequence of the precipitous character of the country and the large rainfall, the construction of these roads was very expensive, requiring heavy retaining-walls, masonry bridges and culverts, &c., across the various streams, much in excess of ordinary requirements.

## The Aqueduct.

The length of the aqueduct is 95⅞ miles, 14⅛ miles being in tunnel (for 50 million gallons per day), 36¾ miles in cut-and-cover (for 50 million gallons per day), and 45 miles in cast-iron siphons (for 10 million gallons per day). At a distance of about 100 yards from the lake on the line of the aqueduct a straining-well, Figs. 6, 7, Plate 2, is sunk in the rock to a depth of about 65 feet. This well is circular, and is lined with concrete; the diameter at the bottom is 37 feet 6 inches, increasing by two set-offs to 40 feet 6 inches at the surface of the ground. On the lake side of and adjoining this well a rectangular valve-shaft, also lined with concrete, is sunk to the same depth as the well. The water is drawn from the lake by a tunnel of the same size and shape as the aqueduct to be described. The invert of this tunnel is 6 feet 3 inches below the original normal level of the lake, the limit fixed by Parliament below which no water may be withdrawn. This tunnel ends at the valve-shaft, the water being conveyed through the valve-shaft to the straining-well by a pipe 42 inches in diameter. This pipe is commanded by two valves, one being worked by hydraulic power and the other by hand-gearing, as in the case of the valves in the tunnel at the outlet of the lake. Provision has been made in the lining of the valve-shaft and the straining-well for drawing off the water from the lake at a higher level whenever the requirements of the city necessitate the further raising of the lake. The

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water is delivered into the straining-well on the outer side of an octagonal screen of strainers 22 feet in diameter and 16 feet high. Seven sides of the octagon are formed by strainers, two of which, one above the other, occupy each side. Each strainer is 7 feet 4 inches wide and 8 feet high, framed in oak and divided into six compartments, each compartment being filled by a small frame (which can be removed as required) holding copper-wire gauze of 900 meshes to the square inch, the gauze being supported by strong copper wire of larger mesh. The strainers are fitted into grooved cast-iron columns 21 feet high, the difference in height between the top of the strainers and that of the columns being made up by stop-planks. These columns, which are stayed to the walls of the well and to a centre column 36 inches in diameter, support two wrought-iron platforms or galleries, enabling the workmen to obtain access to the strainers. Each column is cast with two sets of grooves, one behind the other, so that when it is desired to take out and wash any strainer, a spare strainer can be inserted into the hinder groove and left there until the other is replaced. The eighth side of the octagon is open and is opposite to the entrance of the aqueduct to Manchester. Stop-planks are inserted between the octagon and the walls of the well on both sides of this entrance, so that the water, after passing through the strainers to the centre of the well, flows to the aqueduct. A small hydraulic pump fixed to the wall of the valve-shaft keeps it free from water. As water accumulates a float rises and opens a valve, which admits the pressure-water to work the pump.

To lift the strainers for washing and other purposes, a hydraulic travelling-crane is placed in the building over the straining-well. This crane is attached to and revolves round the column in the centre of the well. The arm of the crane is horizontal, and is supported at the outer end by a triangular frame, which travels round the inside of the building on a rail fixed at floor-level. This frame carries a winding-drum and hydraulic-engine. The engine has two 6-inch cylinders driving direct on to the drum on which the chain lifting the strainers is wound. The power is sufficient to lift a strainer weighing 8½ cwt. from the bottom of the well, a distance of 65 feet, in two minutes. The framework of the crane is of steel, the travelling gear being worked by hand.

At the top of the well the centre column carries radial girders, the outer ends of which rest upon the walls of the well. Upon these girders and around the circumference of the building over the well there is a gangway, 7½ feet wide, formed of cast-iron

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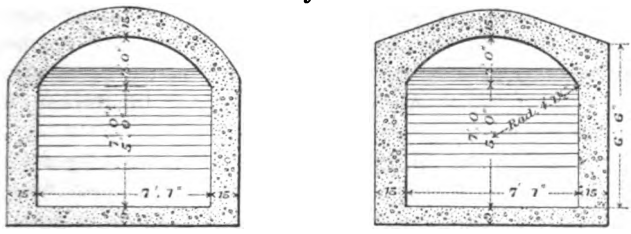
plates chequered on the surface, with a guard-rail at the edge. The rail on which the hydraulic crane travels is also fixed to these girders. Wrought-iron ladders are fixed to reach the different floors in the valve-shaft, and a wrought-iron spiral staircase is provided in the straining-well down to a platform above the mouth of the aqueduct, on which a cylinder working the sluice which governs the water sent to Manchester is fixed. The straining-well and valve-shaft are covered by a castellated building with two wings, in one of which the strainers are washed; in the other stores and tools are kept. The centre column of the straining-well assists in carrying the roof of the building. The supply of water for washing the strainers and working the hydraulic machinery is taken from a small tank constructed on the hillside, and fed from a neighbouring stream. The invert of the pipe at the tank is 61 feet above the floor of the building over the straining-well.

*Figs. 8.*




Tunnelling. Cut and Cover.

SECTIONS OF AQUEDUCT.

Through the wall of the straining-well is laid a short length of pipe 42 inches in diameter, which delivers the water into the aqueduct. This pipe is commanded by a 42-inch sluice, also worked by hydraulic power.

The aqueduct, Figs. 3 and 4, Plate 1, from the straining-well commences with the Dunmail Raise Tunnel, 5,188 yards in length. Some of the other long tunnels are, the Moor Howe 3,040 yards, the Nab Scar 1,419 yards, the Skelgill 1,243 yards, the Grizedale 910 yards, and the Chapel Green 604 yards; and there are many others between 400 yards and 900 yards in length, the total length of tunnels being 14⅛ miles. The greater part of the long tunnels was driven by machinery worked by compressed air.[1] The tunnels, *Figs. 8*, are for the most part lined with 5 to 1 concrete. Where a segmental arch is used, the sides are 5 feet high, and in such

[1] Minutes of Proceedings Inst. C.E., vol. cxvi. p. 162.

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cases the arch has a rise of 2 feet. The width of the aqueduct is 7 feet 1 inch, and the general height is 7 feet. The thickness of the concrete varies according to the nature of the ground passed through. In the floor it ranges from 4½ inches in close rock to 18 inches in bad ground, and in the walls from 12 inches to 18 inches according to circumstances. The depth of the arch is 15 inches. In special cases, however, it was found necessary to adopt stronger sections. A considerable portion of the long tunnels in the Lake District is unlined, with the exception of the concrete floor, which is never omitted; in such cases the width of the aqueduct is 8 feet 6 inches, to meet the increased friction in the passage of the water caused by the irregularities in the rock.

The cut-and-cover, Figs. 3, 4 and 8*a*, portion of the aqueduct was constructed to the same internal dimensions and shape as the tunnels which are lined, the thickness of the lining varying according to circumstances. Manholes with ventilators are provided at intervals of about ¼ mile. The bridges over streams on the cut-and-cover portions are in all cases of masonry, and provision is made at these and other places for the overflow and discharge of the water in the aqueduct. Throughout the tunnels and cut-and-cover sections the fall in the aqueduct is 20 inches per mile.

Wherever the hydraulic gradient is intersected by valleys too deep to be crossed by the concrete aqueduct, the latter terminates in rectangular chambers, described as north siphon wells, Figs. 9, 10, 11, Plate 2, from which the water passes direct into cast-iron pipes laid across the valley, terminating in chambers, described as south wells (see Appendix). There are thirty north wells on the line of aqueduct, the two first in the Lake District being somewhat larger than the others, in consequence of the works in these siphons being designed for three lines of pipes 48 inches in diameter, while in the case of the others there will be five lines 40 inches in diameter. The Act of Parliament provides that within a distance of 9 miles of Thirlmere each pipe shall be capable of delivering not less than 14,000,000 gallons per day. The object of this provision is to reduce the number of pipes, so as to minimise the disturbance in the Lake District which might be caused from time to time by laying additional lines of pipes whenever it should be found necessary to increase the supply to the city.

In each of the north siphon wells there is a valve which, in the event of a pipe bursting, closes automatically, thereby cutting off the supply. This well has been constructed sufficiently large to contain the valves which will be required on the other lines of

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pipe. The arrangements in the wells at the head of the two 48-inch siphons are identical with those for the 40-inch siphons, with the exception of the diameter of the valves and floats, which is 8 inches greater, to correspond with the increased size of the pipes. The well is divided into two main compartments. One of these, the valve-well, which receives the supply from the aqueduct, contains the valves, together with the necessary overflows for dealing with the water coming from the lake when any valve is closed. The other compartment, the float-well, is sub-divided into smaller wells, one for each line of pipes. Each of these wells contains a float, by which the valve commanding that line of pipes is set in motion. The pipe at present laid draws its supply from the centre float-well. The water passes from the valve-well to each float-well separately through cast-iron tubes, one to each line of pipes, set in the concrete floor. The end of the tube in the valve-well is turned up so as to present a horizontal circular orifice 56 inches in diameter, which is faced with gun-metal and upon which the valve closes; the other end in the float-well is turned up in the same manner, and is provided with vertical guides, in which the float rises and falls. The sides of the tube in this well are cast with seven circular orifices, each 15 inches in diameter, through which the water passes to the siphon-pipe. The valve consists of two concentric bell-shaped vessels, the outer of which is 56 inches in diameter and the inner 20 inches in diameter, the latter being only used in charging the pipes. The outer bell is of cast iron and the inner one is of Delta metal. The tops of both bells stand above the surface of the water, so that they form equilibrium valves. The float is hung from a lever 18 feet long, having the fulcrum at one end and the float at the other, the bell-valve being suspended between the two, and distant 4 feet 6 inches from the fulcrum. The fulcrum end of the lever is attached by a Delta-metal pin to a cast-iron box built into the roof of arched recesses in the side of the well, the float end being slung in a guide by chains which pass over pulleys and carry the counterbalance weights. The float, which is made of copper, is 52 inches in diameter, and is connected with the lever by a rod. Passing horizontally through the centre of the large bell, about 6 inches above the seating, there is a rectangular tube, 12 inches by 6 inches, open at the ends; in the middle and on the upper side of which there is a circular orifice 19½ inches in diameter, with a gun-metal seating on which the smaller bell-valve rests when closed. This small valve is connected by a rod through the top of the large bell with a canoe-shaped casting working on

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trunnions on the top of the lever. In this canoe casting, which is 58½ inches long, there is a cast-iron ball 9 inches in diameter, weighing 80 lbs., the rolling of which tilts the canoe and so opens or closes the small valve. The trunnions are not placed at the centre of the canoe, but nearer the valve end, giving a leverage of about 3 to 1. In the event of a burst occurring on the pipe-line the level of the water in the float-well falls, and the float falling with it closes the large bell-valve. The supply to the siphon is by this means cut off, and the water coming from the aqueduct goes to waste over the overflows provided in the valve-well; thus further damage by the burst is prevented.

When the repair on the piping has been made, in order to re-charge the pipe slowly and to give the air time to escape, the small bell-valve is opened by rolling back the ball to the end of the canoe nearest the float; the canoe is thereby tilted on its trunnions and raises the small valve. The water, which has always free access to the rectangular tube in the larger bell-valve, now escapes through the orifice thus opened in it and falls into the tube in the floor, by which it passes to the float-well, and so to the siphon. When the pipe across the valley is fully charged, the water begins to rise in the float-well and lifts the float, thereby gradually opening the larger bell-valve. Meanwhile, the raising of the lever by the float causes the ball in the canoe to roll to the end nearest the valve, thus tilting the canoe to its normal position. This has the effect of closing the small inner valve which is no longer required, the water being now admitted to the siphon through the large bell-valve. The valves are now again in position to cut off the water should another burst occur. Thus the apparatus requires no further attention after the re-charging has once been commenced by rolling over the ball. The arrangement is on the same principle as a ball-tap, but with the supply being shut off instead of admitted by the falling of the float.

The siphon pipe terminates in a chamber on the south side of the valley from which the concrete aqueduct again begins. There is no special feature in this chamber, the end of the siphon pipe, which is bell-mouthed, merely turns up through the floor. For a distance back from the north siphon wells the aqueduct is in many cases made 9 inches higher than usual, in order to give a greater head upon the pipes when the full quantity is passing. All the siphons, with the exception of the first two, are composed of five lines of cast-iron pipes 40 inches in diameter; but for about the last 13 miles of the aqueduct between Hulton and the Prestwich

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reservoir, which consists wholly of piping, the diameter is 36 inches as the fall is greater. The total weight of one line of pipes, 45 miles long, is about 52,000 tons. The pipes were cast by the Staveley Coal and Iron Company, and Messrs. Macfarlane, Strang, & Co., of Glasgow. The 48-inch pipes are 9 feet, and the 40-inch pipes 12 feet long, and vary in thickness between 1 inch to $1\frac{3}{4}$ inch. They are coated with Dr. Angus Smith's composition. They were cast socket downwards with an extra head of metal 12 inches deep at the upper or spigot end, which was afterwards cut off in the lathe. While in the lathe all socket-pipes had the outer rims of the sockets turned down until they projected exactly $2\frac{5}{8}$ inches beyond the body of the pipes, to receive wrought-iron hoops subsequently shrunk on. The pipes were then thoroughly cleaned and gauged to see that they conformed to the specified dimensions. Any pipe varying more than $\frac{1}{8}$ inch in any of the internal diameters, or in thickness in any part, was rejected. Two test bars 1 inch wide, 2 inches deep, and 40 inches long, were cast with each pipe, and were numbered to correspond with the number on the pipe. These were required to carry, without breaking, a weight of not less than 28 cwt. applied at the centre between two supports placed 36 inches apart.

The pipes when tested were filled with coal-tar oil under a pressure equal to a head of water 100 feet greater than that to which they would be subject in work. They were then weighed, the date, number, diameter, length and thickness being entered in a book kept for that purpose. It may be here stated that the position of every pipe on the work is also registered, together with the date on which it was laid, the name of the man who laid it, and the time occupied in running the joint. After the weighing, a wrought-iron hoop, 1 inch thick and $1\frac{1}{2}$ inch in width, and of such a diameter that when uniformly heated to a dull red heat it would just pass on into its place, was shrunk on to the socket. The pipe was then taken without delay to a stove to be heated, preparatory to being dipped vertically into the composition. All the operations described, from the time when the pipes were withdrawn from the moulds to the time when they were dipped, were performed under cover, care being taken to protect the castings from damp and from cooling winds. In the length of 45 miles of pipes, six bursts have occurred, three of which were due to the settlement of the ground in the coal district near Manchester, where there is but little pressure; and the other three were caused by some accident, undetected at the time, having occurred to the pipes in transit between the operations of

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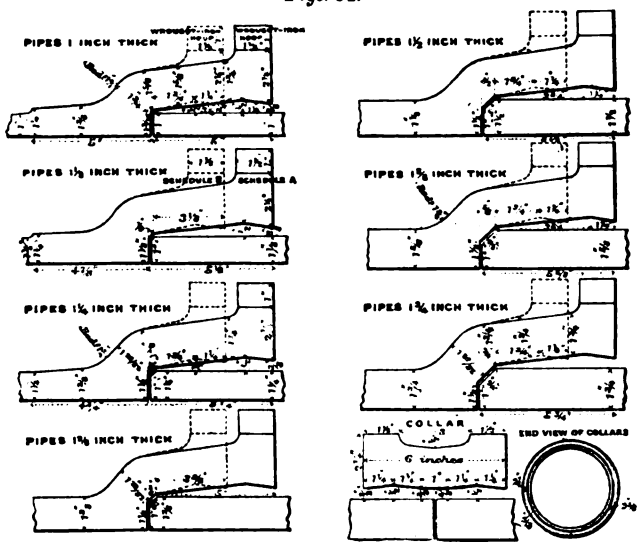
manufacture and laying. In these cases the automatic valves hereafter described came into operation and satisfactorily fulfilled the purpose for which they were provided by cutting off the supply when the burst occurred.

Three types of pipe-joint were used, *Figs. 31.* It was considered that plain cylinders, joined with collars 6 inches wide, were less liable to be in a condition of internal stress than ordinary socket-pipes, where the mass of metal in the socket is considerable compared with the section of the barrel. This pattern of pipe-joint was therefore used in moderately flat ground. On sloping ground,

*Figs. 31.*




¼ full size. Pipes 1¼ inch thick.

SECTIONS OF SOCKETS AND COLLARS FOR 48-INCH, 40-INCH AND 36-INCH PIPES.

where some difficulty might have occurred in making collar-joints, socket-pipes were used—the socket varying in depth between 3 inches and 3⅝ inches according to the thickness of the pipe. In colliery districts, the collars used were between 8 inches and 12 inches wide, and the sockets were 5 inches deep. In all cases the joints were run solid with lead, no yarn being used; a spring ring inserted in the pipe while the joint was being run, prevented the lead from entering. In all cases the sockets and collars are designed so that the lead may be ⅜ inch thick at the face and ½ inch thick at a distance of 1¼ inch from the face, tapering to ⅛ inch at the end. By this means blown joints are avoided.

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For turning angles, whether in plan or section, double-socketed bevel castings were used, ranging in length up to 13½ inches measured on the axis. The angles to which they were cast varied between 1° and 10°. Where larger angles than these occurred on the pipe-line, as many bevels were used as would give the required angle, and were connected by spigot pipes 3 feet long. In the case of most of the angles the bevels were surrounded with concrete.

The longest siphon, Figs. 3, 4, Plate 1, is that across the valley of the River Ribble, and is 9½ miles in length. The greatest head of water, 427 feet, is on the siphon across the valley of the Lune near Lancaster. Wherever the cutting for the pipes exceeded 12 feet in depth, they were surrounded with concrete to a height of 12 inches above the pipe. In cases where the pipes were laid to an extremely steep inclination, in order to prevent movement, thrust-rings having an external diameter of about 54 inches were placed against the sockets at suitable intervals and surrounded with concrete. With few exceptions the pipes are carried over rivers, the longest bridges being those over the rivers Lune and Ribble, Figs. 15 and 16, Plate 3. These two bridges are alike, except that the former is on the skew; the following description therefore applies equally to both. Although only one line of pipes is at present laid, these bridges are made the full width for the five lines. There are three 70-foot spans, and the pipes are primarily carried by three cast-iron arched ribs, each in three sections 2 feet deep, spaced 13 feet 9 inches apart. These ribs spring from cast-iron bed-plates let into the masonry piers and abutments, and they are connected together at a distance of 12 feet on either side of the middle of the span, by steel cross-girders 20 inches in depth with a plate web ⅜ inch thick, each flange being composed of two angle-bars, 4 inches by 4 inches by ⅝ inch. At a distance of 22 feet 7½ inches on each side of mid-span the arched ribs are again connected by a cast-iron girder 2 feet deep. Six longitudinal rolled-steel girders, 14 inches by 6 inches, are carried at their outer ends by the masonry and by the two steel cross-girders near the middle of the span. The four girders nearest the centre-line are 5 feet 3 inches apart, the distance between the outer girders being 4 feet 11½ inches, and the six lines are connected by transverse steel beams 6 inches by 5 inches by ⅜ inch. Upon the upper flange of each of the longitudinal girders, and 1 foot 7¾ inches on each side of the middle of each pipe, are bolted a pair of castings which form the paths of two rollers 4¾ inches diameter; these rollers span the distance between the two longitudinal girders, and carry a cast-iron seat, 4 feet by 1 foot 2 inches, upon which the

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pipes rest. Upon each of the two middle longitudinal girders, five columns, formed of steel angle-bars, are carried, and support two longitudinal gangway girders 10 inches by 6 inches; upon these two girders rests the footway formed of bar-iron gratings, on either side of which is a handrail. The arched ribs on the outside have moulded flanges, and carry cast-iron spandrels and parapet of an ornamental character; the top of the parapet in the centre of the bridge is 6 feet 3 inches above the top of the arched rib, and the ornamental facework is supported by steel angle-bars riveted to the gangway girders. The piers and abutments are of blocking-faced masonry with dressed ashlar mouldings; and where vertical angles occur at the ends of the bridges, each pipe is anchored to the masonry by wrought-iron straps and bolts. On the upper flanges of the gangway-girders are bolted bridge-rails, on which travels a set of shear-legs for lifting out and replacing a pipe in case of burst, spare pipes being always kept conveniently near the bridge.

There is a third bridge, also of three spans, of the same type, over the River Irwell at Agecroft, near Manchester. In the coal district, for crossing railways, &c., there are seven plate-girder bridges, Figs. 21 and 22, Plate 3, with closed floor and ends; so that in case of a burst the escaping water is retained in the bridge and flows away by a waste-pipe provided for that purpose. There is no special feature in the design of these bridges, which are constructed of mild steel. Where the pipes pass under railways, subways are constructed into which access is obtained by a manhole at each end. These manholes are covered by bar-iron gratings, so that, in the case of a burst occurring in the subway, the water can flow out at the gratings and escape by a channel cut in the ground for that purpose. As in the case of the pipes, so with the other ironwork contracts, the greatest care was required in every step of the manufacture.

The number of valves upon the 45 miles of main pipe is very large, including stop-valves, self-acting valves, reflux-valves, air-valves, and mushroom-valves. The largest stop-valves, Figs. 30, Plate 3, ten in number, are those on the 40-inch pipes, the thickness of metal in the casing varying according to the pressure to which they are subject. The casing consists of three flanged castings strongly bolted together, the lower part being in two portions surmounted by a cap. The waterway of each valve is divided into three openings, the centre one being of a clear width of 5½ inches. The division is formed by two vertical cast-iron ribs, bolted at the bottom to fins cast on the inlet and outlet castings. At the upper

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end each rib is flanged out until it touches the sides of the vertical portion of the casing, thereby forming a diaphragm which completely closes in the top of the waterway, except that part required for the free passage of the doors. A lead joint is made round the edges of the diaphragm. Above the flanging out, the ribs are continued as far as is necessary to form guides for the doors. There are three stuffing-boxes in the cap, one for the lifting-rod of each door. The lifting-rods are formed of gun-metal tubes turned to an outer diameter of 5½ inches and ¾ inch thick. The thickness of the upper end of these tubes is 1½ inch, and upon the inside of this portion a square screw-thread of ½-inch pitch is cut, in which the gun-metal lifting-screw works. The entablature, which supports the screw-spindles and the gearing, is carried by four cast-iron pillars standing on bosses which are cast upon the cap of the valve-casing. The entablature is secured to the bosses by long bolts cottered into them, passing through the pillars and held by nuts at the top of the entablature. The centre spindle is worked by worm-gearing. These valves are anchored by a pair of steel anchor-rods in order to prevent any movement in the pipes, Fig. 14, Plate 2. The rods are 4½ inches wide and 2¼ inches thick, and have an eye on their upper ends through which pass the trunnions of a heavy cast-iron thrust-ring. This ring is bolted round the pipe and abuts against a heavy casting attached to the valve; to the other end of the rod is fastened a cast-iron anchor-plate buried in concrete.

Self-acting valves, Figs. 27 and 28, Plate 3, are fixed on the northern or Thirlmere sides of the longer siphons; there are seven on the 40-inch pipes and two on the 36-inch pipes. Should a burst occur on the pipes below the level of these valves, the water is automatically cut off and damage to lands, &c., avoided. The body of the valve consists of two tubular castings forming the water-way. In the flanges by which these castings are bolted together, sockets are formed for the reception of the Delta metal stuffing-boxes in which the trunnions of a cast-iron disk-valve revolve. This disk-valve is hollow, of double convex shape, and forms one casting with the trunnions, which are also cast hollow, the thickness of metal being 2½ inches in each case. The distance between the outer surfaces of the disk at the vertices of the convex curves, is 10 inches, diminishing to ¾ inch at the edge of the disk. The outside diameter of the trunnions, where they pass through the stuffing-boxes, is 7¼ inches, and they are cased with gun-metal ⅜ inch in thickness. The touching-surface at the edge of the disk is truly faced, and comes to rest against gun-metal stops, which are sunk



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⅜ inch into the cast-iron body and fastened by gun-metal screws ½ inch diameter, 1½ inch apart. The distance between the ends of the trunnions is 6 feet 5 inches; at the ends they are reduced in diameter to 6 inches and receive two cast-iron pulleys, the outside diameter of which is 1 foot 11½ inches. These pulleys are actuated by chains, to the ends of which weights are attached. In the case of one pulley, the chain, after passing round it, is attached to the rod of a piston working in a horizontal cataract cylinder 10½ inches in diameter and 2 feet long, bolted to the longer of the two castings forming the body. This cylinder contains a mixture of glycerine and water in the proportion of one part of the former to two of the latter.

The exhaust from the cataract-cylinder is regulated by a lever attached to a small cock placed on a line of copper pipe communicating through Delta metal T-unions with each end of the cylinder, and operated by a Delta metal grooved stud, attached to the side of the chain-wheel. The lever has two arms of unequal length. The free end of the longer arm rests in the groove of the stud on the chain-wheel, the shorter arm being attached to the spindle of the cock. The centres and lengths are so arranged that the throttle-cock is very gradually closed towards the end of the stroke of the piston, without being quite closed when the main-valve is shut. A small Delta metal vessel, holding a reserve of liquid, is supported on an iron bracket on the edge of the body casting, and is connected by a short length of copper tube to a T-union fixed over the end of the cylinder farthest from the chain-wheel. A small force-pump is placed over the cataract-cylinder, by which the disk-valve is brought back to a horizontal position. The longer of the two castings forming the body of the valve has a branch 15 inches in diameter, to which is bolted an air-vessel 7 feet 6 inches high, 2 feet 11 inches in diameter, and 2 inches thick. Two hollow tapering bosses, cast diametrically opposite on the inside of the air-vessel receive the shaft, which carries a malleable cast-iron lever hanging down into the waterway, its range of motion being limited by two spurs. To the end of this lever is riveted a plate-iron disk 21½ inches diameter. To one end of the shaft is fixed a lever, from which weights are suspended sufficient to balance the normal pressure of water against the disk, and to hold the lever firmly against the upstream side of the branch which carries the air-vessel. Should, however, a burst occur on the line of pipes, the weights are no longer able to balance the pressure on the disk, which is moved by the water until the spur touches the opposite side of the air-

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branch. The lever which carries the weights is thus lifted, and the upper end of another lever, which has been resting against a stud upon it, falls until it rests on the shaft. The lower end of this second lever which has been retaining the chain-pulley in position, then releases the chain-pulley, and allows the weights which it carries to set the disk-valve in motion.

For charging the air-vessel, a small Delta metal domed cylindrical vessel is bolted to a bracket cast on the body of the valve immediately below the air-vessel, and connected at the bottom by short copper tubes with the air-branch, and at the top with the main air-vessel. A three-way cock is placed on each of the tubes, and linked with the others. When it is desired to increase the quantity of air in the main air-vessel, the two cocks are, by a hand-lever, closed to the air-vessel and to the water in the air-branch, but are open to the atmosphere and the subsidiary vessel; thus any water contained in that vessel flows out to waste through the lower cock, while air enters through the upper cock. The cocks are then set so as to be closed to the atmosphere, and open to the water and main air-vessel. The charge of air contained in the subsidiary air-vessel then bubbles up into the main air-vessel. These valves are anchored similarly to the others, but in one direction only.

The reflux valves, Figs. 29, Plate 3, are placed on the ascending or southern ends of the long siphons, and are ten in number. Each is made up of three castings, an inlet, a centre or valve casting to which the doors are attached, and an outlet. The centre casting is divided into five openings by strong horizontal division-bars forming a part of the casting. The middle opening is 9 inches in height and 4 feet 1 inch in width; the two openings adjoining the middle one are 9 inches in height and 3 feet 6 inches in width; the upper and lower of the five openings are 4½ inches in height, and 16 inches in width. Each of the five openings is covered by a cast-iron door, 1¼ or 1 inch thick according to size (the larger doors being strengthened by ribs on the back), hung by two hinges cast on the division bars and on the body of the casting. All meeting faces are lined with Delta metal, 1 inch wide and ¼ inch thick, attached by screws ⅜ inch diameter and 1½ inch apart. Each door is hung with two wrought-iron straps to turned and grooved Delta metal axles, the eyes of the straps being bored and bushed with Delta metal. These valves are anchored in one direction only.

The air-valves, Figs. 31, Plate 3, are of the ball type, but a variation in the usual design is introduced in order to shut off the water



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from the balls, whenever it is desired to remove the latter for repair. This is effected by an inverted mushroom valve, placed in the main air-passage from the pipe, just below and between the balls. The spindle is carried up between the balls, and passes through a stuffing-box in the cover.

Valve-houses have been built over the large stop-valves and self-acting valves. They are large enough to cover the five lines of pipes in the complete scheme. The roofs are of glass, fixed in wrought-iron framing. Wrought-iron girders are fixed in the houses, capable of carrying blocks and tackle for raising any parts of the valves which may require repair. Wicket gates have been placed in every fence crossed by the line of aqueduct between Thirlmere and Prestwich. Watchmen are stationed at intervals along the line, and arrangements are in progress for telephonic communication between Thirlmere and Manchester, and between the men on the line of works.

## Reservoir.

The Prestwich reservoir, at the end of the aqueduct near Manchester, has an area of 4½ acres, and contains 21 million gallons. It is lined throughout; where clear of the embankments the lining is composed of a course of 3-inch bricks set in asphalt, founded on 15 inches of concrete; on the centre-lines of embank ments the usual puddle-wall is used, the puddle being taken under the inner slope and tied into the concrete and brick lining. The water from Thirlmere is admitted by the cast-iron pipes into a masonry inlet-well, built on the centre-line of the embankment, from which it flows over a weir 21 feet wide into the reservoir. The outlet to the city is formed by a group of four wells, and a cleansing- or waste-well on the centre-line of the embankment. The first or outlet well, which communicates freely with the reservoir, contains the vertical overflow standpipe, 42 inches in diameter, from the foot of which a pipe, 27 inches in diameter, passes under the floors into a circular cleansing- or waste-well 15 feet in diameter. From the outlet-well the water flows right and left through two cast-iron pipes, 30 inches in diameter, respectively 12 feet and 23 feet 6 inches below top water-level. These are commanded by sluices and deliver into two circular straining-wells 32 feet in diameter. Each straining-well contains a ring of strainers, as at the straining-well at the lake, from the outside of which the water flows into the middle; whence it is withdrawn into the fourth, or supply well, by a pipe 36 inches in

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diameter. Each straining-well has a scour-pipe delivering into the cleansing-well. Any strainer which it is desired to wash is lifted from the straining-well and lowered into the cleansing-well, in which there is an open floor 9 feet below the surface. All the wells are connected for scouring purposes to the waste-pipe from the reservoir, and are covered with cast-iron plates.

The works comprised in the Thirlmere undertaking were let in nine contracts, and the ironwork in eighteen contracts, with separate contracts for painting. Portland cement concrete was used throughout the works, the quantity amounting to more than 100,000 tons.

## Cost of the Works.

The character of the country through which the aqueduct passes is so varied and so differently affected by local circumstances that it would be impossible to state an average price per lineal yard for the work. The aqueduct begins at the lake at an elevation of 527 feet above Ordnance Datum, and for a considerable portion of its length is much above the general level of the country, the cost of construction being thereby materially increased. In the case of tunnels, the contract price paid for driving ranged from £7 to £10 15*s.* per lineal yard; and for the concrete lining, where 15-inch side-walls and arch and 9-inch invert have been used, from £3 10*s.* to £4 18*s.* per lineal yard. In cut-and-cover, the price paid for the construction of the aqueduct in concrete for the same section of work as in the tunnels, ranged from £5 5*s.* to £8 10*s.* per lineal yard.

The contract prices for the pipe-laying were as follows:—

| | Per Lineal Yard. |
|---|---|
| | £ *s.* *d.* |
| 48-inch pipes . . . . . | 6 15 0 |
| 40 „ . . . . . | from 4 0 0 to 5 10 0 |
| 36 „ . . . . . | 3 15 0 |

These prices are average prices for the various thicknesses of pipes and the different kinds of joints used. They include the cost of the pipe, the laying and jointing and incidental expenses connected with the trench, valves and discharge-pipes; but they do not include the cost of valves, bridges, wells and similar special works.

The total cost of the works up to the date of the opening was about £2,800,000. This sum includes parliamentary expenses (which were exceptionally heavy, in consequence of the deter-

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mined opposition to the scheme and expenditure of every kind. The four lines of pipes yet to be laid, together with diversion of drainage at Thirlmere, will cost about £1,600,000, bringing the cost of the complete undertaking to about £4,400,000.

Up to the time when the Act of Parliament was obtained Mr. J. F. L. Bateman, F.R.S., Past-President Inst. C.E., was the Engineer-in-Chief to the Corporation of Manchester. The preparation of the Thirlmere scheme for Parliament was entrusted by him to the Author, who had been in his office from the year 1843, and who having acted for many years as his representative in the North of England, subsequently became his partner. In the year 1885 the Author was appointed Engineer-in-Chief by the Corporation to design and carry out the works now described.

The Paper is accompanied by twenty-five drawings and cartoons, from which Plates 1, 2 and 3, and the *Figs.* in the text have been prepared.

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# APPENDIX.

## Siphons.

| No. | Name. | Length. | No. | Name. | Length. |
|---|---|---|---|---|---|
| | | Yards. | | | Yards. |
| 1 | Scandale . . . | 280 | | Brought forward . | 32,519 |
| 2 | Stock Gill . . . | 558 | 17 | Street Brook . . | 720 |
| 3 | Holbeck . . . . | 312 | 18 | Holmewood . . . | 208 |
| 4 | Troutbeck . . . | 904 | 19 | Grizedale . . . | 323 |
| 5 | Kent . . . . . | 887 | 20 | Calder . . . . | 1,078 |
| 6 | Sidehouse . . . | 570 | 21 | Brock . . . . | 984 |
| 7 | Mint . . . . . | 5,752 | 22 | Ribble . . . . | 16,600 |
| 8 | Singleton . . . | 584 | 23 | Whaves Brook . . | 879 |
| 9 | Beehive . . . . | 5,218 | 24 | Black Brook . . | 224 |
| 10 | Sillfield . . . . | 380 | 25 | Heapey . . . . | 1,120 |
| 11 | Warth . . . . | 261 | 26 | Yarrow . . . . | 506 |
| 12 | Lupton . . . . | 2,067 | 27 | Shaws . . . . | 222 |
| 13 | Keer . . . . . | 7,857 | 28 | Douglas . . . . | 767 |
| 14 | Lune . . . . | 4,762 | 29 | Pearl . . . . | 720 |
| 15 | Conder . . . . | 218 | 30 | Middle Brook . . | 22,189 |
| 16 | Wyre . . . . | 1,909 | | Total length . . | 79,059 |
| | Carried forward . | 32,519 | | or 44 miles 1,619 yards. | |

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(*Paper No. 2975.*)

# "The Vyrnwy Works for the Water-Supply of Liverpool."[1]

By GEORGE FREDERICK DEACON, M. Inst. C.E.

IT is obviously impossible, within the limits of a Paper suitable for publication in the Proceedings of the Institution, to describe each part of the Vyrnwy Works. The Author proposes, therefore, to rest satisfied with presenting a general and comparative account, and to refer to details only where they involve distinct novelty or points which appear to him useful for future guidance.

## HISTORICAL.

Having, at the instance of the Corporation of Liverpool in 1876–7, made an investigation concerning the water-supply available from various valleys and lakes to the north of Liverpool, and from several valleys in North Wales, the Author in 1877 reported upon two sources, namely Haweswater in Cumberland and the River Vyrnwy in Montgomeryshire. In these reports he claimed for Haweswater nearly every advantage that Liverpool could desire; but concerning the Welsh project he wrote, "the Vyrnwy possesses all the more important advantages of Haweswater, with some advantages which Haweswater does not possess."

The Vyrnwy is a tributary of the Severn, formed from the junction of many streams in an alluvial tract some 780 feet above the sea, supplied from an average annual rainfall exceeding 70 inches, and surrounded by mountains rising to a height of 2,000 feet. So considerable a volume of pure water at so great an elevation had not escaped the notice of the late Mr. J. F. Latrobe Bateman,[2] who had included the area in his North Wales project for the supply of London laid before the Royal Commission on Water-Supply of 1867–9. It is interesting to notice also that the late Mr. Hamilton Fulton[3] laid before the same Commission a very excellent

[1] The discussion upon this communication was taken in conjunction with the preceding one by Mr. Hill descriptive of the Thirlmere supply for Manchester.

[2] Report of the Royal Commission on Water-Supply, 1869, vol. i. pars. 4–40.

[3] *Ibid*, par. 54.

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project for the supply of the Metropolis from South Wales, which included the area now being utilized for the supply of Birmingham.

Between two such good things as Haweswater and the River Vyrnwy it was not in human nature—certainly not in municipal nature—to avoid differences of opinion, and two strong parties championed the two schemes respectively. However, the Author, having further investigated and surveyed the Vyrnwy project, reported in greater detail on the 1st August, 1878, and again recommended its adoption. But the advocates for the northern scheme were still dissatisfied, and in February, 1879, the late Mr. Thomas Hawksley and the late Mr. Bateman, Past-Presidents of the Institution of Civil Engineers, were respectively asked to reply to a series of questions touching the relative advantages of the two projects in various particulars, physical, chemical and financial. Happily there was no want of agreement in essential particulars, and the balance of their opinions was strongly in favour of the Vyrnwy.

This view having been adopted by a majority in the Corporation of Liverpool, the Author was instructed, during the summer of 1879, to complete the surveys and prepare the parliamentary plans, and from September, 1879, the late Mr. Hawksley acted jointly with him in promoting the passage of the Bill through Parliament. On the 6th August, 1880, the Act received the Royal Assent, and on the 14th July, 1881, the memorial stone recording the commencement of the works was laid. In 1885, Mr. Hawksley retired from the work, and the undivided responsibility fell upon the Author. In July, 1892, the undertaking having been practically completed was opened by the Duke of Connaught.

The beginning of the works, and the completion of Lake Vyrnwy and of the aqueduct respectively, have been recorded in the terse and stately language which will still be read when, in the nature of things, the principal uses of the works—though not the works themselves—shall have ceased to be. The first inscription is on the frieze of the southern tower of the masonry dam, Fig. 5, Plate 4, and records, as follows, the year before the permanent works were begun, and in which the Act of Parliament authorizing them was passed,

OPVS · INCHOATVM
MDCCCLXXX

while the frieze of the tower, 650 feet to the north, chronicles the passage of a decade thus:—

OPVS · ABSOLVTVM
MDCCCXC.

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Lastly on the frieze of the Norton Tower, Fig. 25, Plate 5, and *Fig. 27*—the most northerly balancing reservoir of the aqueduct—from which on a clear day Liverpool may be seen, the story of the work is briefly told as follows :—

HAEC · AQVA
DE · SABRINAE · FONTIBVS · DERIVATA
LXXX M : PASS : PER · ARDVA · AC · PLANA
CAMBRENSIS · ET · INTERIACENTIS · AGRI
AD · VRBEM · LIVERPOL :
IMPENSIS · MVNIC : PERDVCTA · EST
A : S :
MDCCCXCII

## General Features.

The Reservoir, now known as Lake Vyrnwy, differs only in magnitude and details of construction from other numerous reservoirs employed for impounding flood waters and conserving them for use in periods of comparative drought.

Of aqueducts on the other hand, there are broadly two kinds and their combinations.

(1) The open or closed culvert contouring the hillsides and passing across the valleys by bridges, with the water flowing at the hydraulic gradient, of which the ancient Roman aqueducts are the best known types.

(2) The entirely closed conduit, subject to the unbroken pressure from end to end due to the initial head of water, as in most short aqueducts of the cast-iron age and in some long aqueducts of wrought-iron or steel in America.

(3) The combination of types (1) and (2), in which the hydraulic gradient is followed wherever tunnelling or contouring is practicable, and in which the valleys are crossed by inverted siphon-pipes under pressure, as in the case of the Loch Katrine Aqueduct for the supply of Glasgow, and the Thirlmere Aqueduct for the supply of Manchester.

(4) The combination of types (1) and (2), in which the hydraulic gradient is only followed where it is necessary to tunnel, and is elsewhere only reached where the pressure is purposely broken by balancing-reservoirs between the source and the service-reservoir. The Longdendale Aqueduct for the supply of Manchester, and the Rivington and Vyrnwy Aqueducts, both for the supply of Liverpool, are examples of this treatment.

The Vrynwy Aqueduct is shown in plan at Fig. 1, and in longi-

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tudinal section at Fig. 2, Plate 4, with the Vyrnwy reservoir at the southern end, the Prescot service-reservoirs at the northern end, and intermediately, besides other special works, the four tunnels, five balancing-reservoirs, six river crossings, thirteen railway crossings, and six canal crossings including the Weaver Navigation and the Manchester Ship Canal.

## The Vyrnwy Reservoir.

Lake Vyrnwy is chiefly remarkable as the largest artificial reservoir in Europe, and as the first in Great Britain in which a high masonry dam was employed. The valley is the site of a post-glacial lake basin, the lower, or south-eastern, extremity in the Lower Silurian, and the upper, or north-western, extremity in the Upper Silurian rocks. In 1876–7, when the Author first visited it, the River Vyrnwy wound through an alluvial tract of gravel, sand and peat, extending towards the source for about 5 miles from the narrower part of the valley, where the almost sluggish river gave place to a rapid stream. The maximum depth of this rock basin below the alluvium is unknown, but there are indications that, as in the case of other glacial basins, it is considerable. To determine the highest part of the then hidden rock bar near the lower end of this alluvial strath, 177 borings and probings, and thirteen shafts were sunk, and, by means of these, actual contours were drawn, and a model made of the surface rock. These contours showed that the maximum depth of rock, sound or unsound, along the shallowest bar was 40 feet to 45 feet below the surface, from which it increased higher up the valley to unknown depths, a fact entirely consistent with the glacial origin of the basin. When, in the course of excavation, the dislocated rock was subsequently removed from this bar, there was exposed to view the watertight portion of the natural dam by which the post-glacial lake had been impounded. This watertight rock was on the average 6 feet to 7 feet lower than the surface rock which the contours had shown, and the deepest point was about 60 feet below the river bed. The alluvium had not only silted up the basin formerly occupied by water, but had been carried by the floods of the river which subsequently traversed it, to a further height of 40 feet or 45 feet at the site of the dam, so that while the depth of the modern lake at the dam is only 84 feet, the dam at one point of its base is subject to the full head of 144 feet.

Below the sill of the dam and above the outlet to the aqueduct, Lake Vyrnwy contains 12,131 million gallons. Its area is 1,121 acres.

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In a single foot of depth immediately below the overflow, the lake contains about 304 million gallons; 5 feet lower a foot of depth contains 292 million gallons; at 10 feet it contains 281 million gallons, and at 15 feet a foot contains 270 million gallons, figures which clearly show the exceptionally favourable character of the basin as a reservoir. The average cross-section of this remarkable sheet of water does not differ widely from a horizontal base 2,000 feet wide, with a depth of water over it of 70 feet, and end slopes of $2\frac{1}{4}$ to 1.

## The Vyrnwy Masonry Dam.

In 1881 there was probably no high masonry dam in Europe so far watertight that an English engineer would take credit for its construction. Methods not hitherto practised were clearly necessary if water-tightness was to be secured. Leakage might not indicate danger, but it was wholly inadmissible in a structure to impound more than 13,000 million gallons of water on a river 200 miles in length and passing such towns as Shrewsbury, Worcester, and Gloucester. This and other considerations led to the decision to avoid any division of responsibility by carrying out the impounding works without the intervention of a contractor. Great care, moreover, was taken to avoid the combination of supervision such as a contractor's staff would exercise for the purpose of economy and despatch, with inspection for the attainment of a high standard of workmanship. All such conflicting functions were kept separate, and the general administration was very much what the separate administrations of the staffs of the engineer and contractor would otherwise have been.

*Design.*—The cross section of the Vyrnwy dam is shown at *Figs. 3*, and is dotted in Fig. 4, Plate 4. The design of this dam has been already referred to in the Proceedings of the Institution and the reasons for the departure of its cross section from the form which, upon certain not altogether true hypotheses, mathematical analysis produces, have been discussed.[1] The half-elevation is shown at Fig. 5, Plate 4.

*Excavation.*—The great width of the base—about 127 feet at the widest part of the intended dam—precluded timbering the sides of the excavation. They were therefore sloped at about 1 to 1. The lower levels consisted largely of enormous boulders, and, therefore, with the exception of a single steam-navvy, manual

[1] Minutes of Proceedings Inst. C.E., vol. cxv. pp. 112-120.

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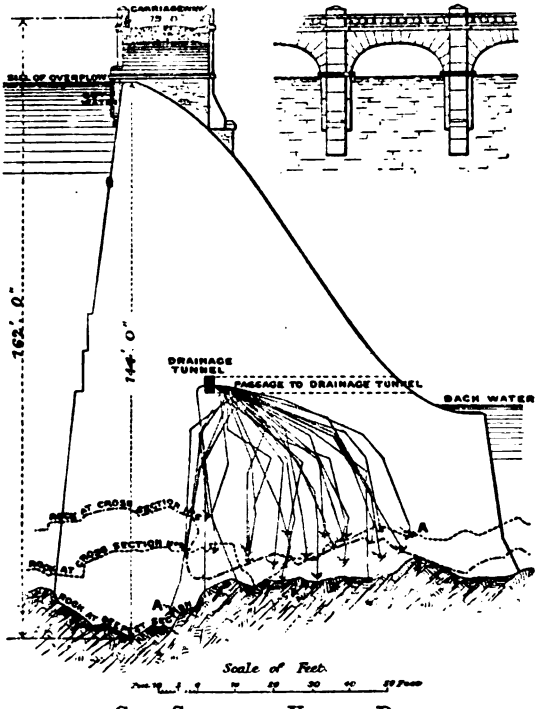
labour was used. The work was usually carried on night and day, electric light to the extent of about 30,000 candle-power being employed at night.

*Foundations.*—The rock at the bar already described had a dip towards the west. As the glacier moved towards the south-east it had tended to separate the rock at the principal planes of cleavage which were approximately normal to the beds, and masses weighing hundreds of tons, broken from their beds and moved some distance

*Figs. 3.*




CROSS-SECTION OF VYRNWY DAM.

down the valley, or only just detached, were met with. All these, so far as they occupied the site of the intended base, were, of course, removed, leaving the structure indicated at *Figs. 3* and *6*, and at Fig. 4, Plate 4. The surface rock was met with approximately at the depths indicated by the rock contours, and was almost completely covered with striæ nearly parallel with the axis of the valley precisely as the glacier had left it.

Although no visible springs of water issued from the beds of

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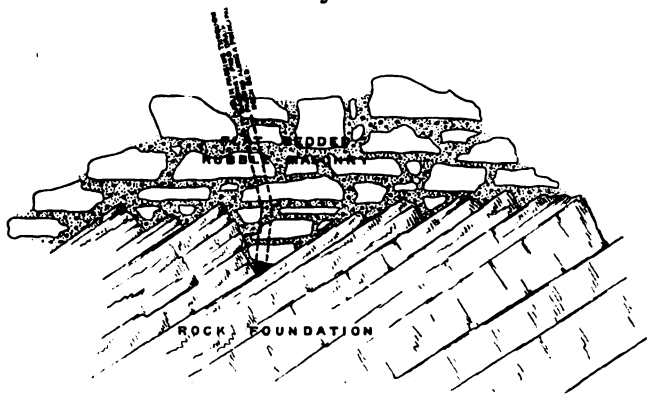
rock thus exposed, it was by no means certain that, when the reservoir was formed and the head on one side became 144 feet, springs subject to that pressure would not occur. Moreover, a mere moisture, rapidly evaporated when exposed to the air, might, when sealed down, acquire a pressure from the adjoining hills of far more than that due to the intended level of the lake. The late Mr. T. Hawksley had, from the beginning, laid great stress upon the necessity of rendering any such accumulation of pressure impossible, on the grounds that it might assume considerable importance as one of the forces tending to overturn the dam, and the Author agreed with him in thinking it desirable to provide relief drains, which, so far as he is aware, had not been done in connection with any former masonry dam. Accordingly, along

*Fig. 6.*




SECTION OF ROCK SURROUNDING A DRAIN IN FOUNDATIONS OF VYRNWY DAM.

the base of each of the more important beds of rock, not within 15 feet of the face of the dam, a drain was formed by the masonry between 6 inches and 9 inches square, and from these drains funnels were carried up in different vertical transverse planes of the dam to above the backwater level. The twenty-seven funnels which occur in a length of only 66 feet of the dam at its deepest part, are shown at *Figs. 3*. The funnels all issue at the side of a longitudinal tunnel 4 feet 3 inches by 2 feet 6 inches, so that the flow from each, if any, is rendered visible. From this tunnel a cross tunnel, shown in the same figure, serves as an outlet for the water from the rock and as a passage to the main tunnel. At *Fig. 6* a section of the rock and masonry surrounding a single drain is shown to an enlarged scale. The quantity of water thus

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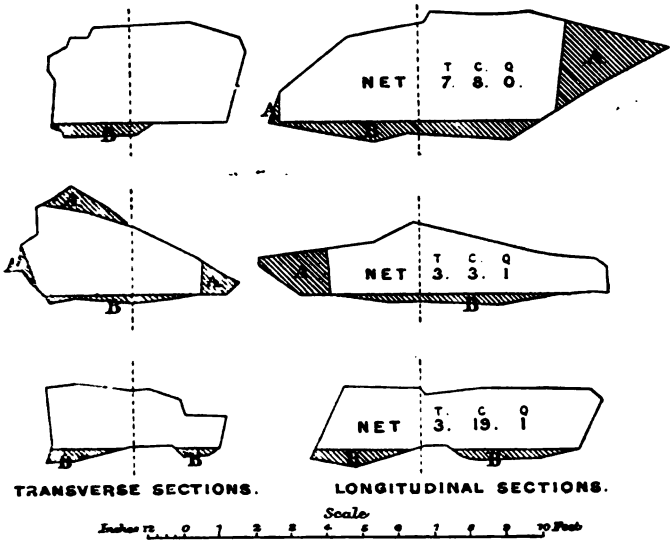
discharged from the foundations has always been very small, and it fluctuates very slightly. For the central length of 214 yards, representing a foundation area of 8,000 square yards, it is only about 2 gallons a minute, including the leakage, if any, through the dam, while the discharge from the end portions is relatively smaller.

*Masonry.*—The rock available for the masonry was clay-slate from the Caradoc beds of the Lower Silurian. In point of quality it was excellent, in point of quarrying properties execrable. The planes of cleavage made acute angles alike with each other and the beds, and few shapely stones could be obtained except at

*Figs. 7.*




the sacrifice of a large portion of each block. Excluding the covering of earth, the spoil heap of stone rejected as unsuitable, or worked from accepted blocks, was nearly 700,000 tons. But the stones when sufficiently shaped, were everything that could be desired. Several stones, as measured on the ground both before and after being prepared for the hearting, are shown in longitudinal and cross section at *Figs. 7.* They indicate fairly well by the external lines the character of the blocks as quarried, and by the shaded areas the portions removed to make them available for the hearting of the work. It should be explained that such points as those marked A were generally removed with the sledge-hammer,

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thus leaving jagged surfaces, only diagramatically represented in the *Figs.* The beds or bases of all stones which could not be easily lifted by one man were, however, worked to a flat, but very rough and indented surface, by the removal of such parts as those marked B. These parts were, in most cases, quite sufficiently reduced by means of a steel set, like that used by smiths, struck with a two-handed hammer, though in some cases, depending on the grain of the stone, the ordinary punch or pointed chisel and single-handed hammer were necessary.

Exclusive of the stones in the superstructure, which were generally larger, the proportions of different sizes of stones set by the cranes may be gathered from the following net weights:—

| | |
|---|---|
| Under 2 tons . . . . . | about 46 per cent. |
| 2 „ to 4 tons . . . | „ 21 „ |
| 4 „ „ 10 „ . . . | „ 33 „ |

In the 46 per cent. under 2 tons is included all the spalls and broken stone used for filling.

The face stones were subject to the same conditions as the hearting stones, except that their faces were drafted to rectangles, and the upper beds and joints roughly worked for about 1 foot from the face. The size and general character of the face work may be gathered from *Fig. 8*, taken from a photograph.

Masonry—especially when constructed with stones of such large size—subject to a considerable head of water, can only be made watertight by flat bedding, and with mortar of such consistency that it will flow under pressure without any separation of the sand from the cement. The mortar must in no case have the consistency of grout, but rather of plastic putty. In relation to this matter the first and only practical difficulties connected with the Vyrnwy masonry arose. Portland cement was, naturally at that time, decided upon, though it was known then as now that, *cæteris paribus*, the mortar would be harsher and more difficult to bed large stones upon, than would be the case with hydraulic lime. There was no natural sand available, except that of the valley—produced mainly from the denudation of the clay-slate and grit rocks of the Silurian formations, and with such sand, thoroughly washed by machinery, and Portland cement, the first of the mortar was made. Upon this, with infinite difficulty, by dint of twisting the stones backwards and forwards, in addition to driving them down by the simultaneous strokes of many two-handed mallets, perfect bedding was attained; but meanwhile experiments in another direction were in progress. It was found

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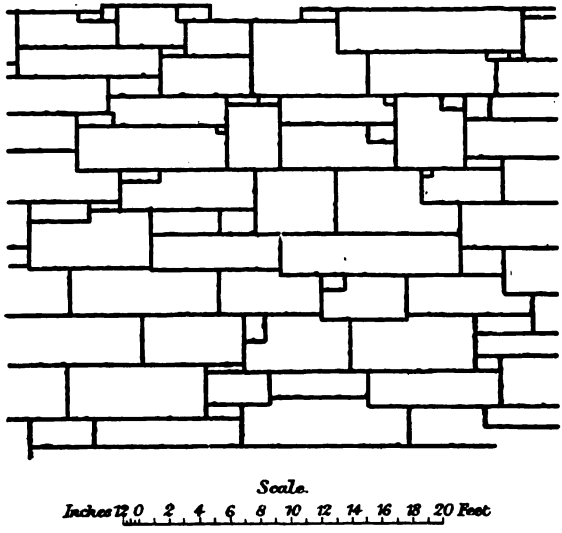
that stone from the quarry spoil heap—of which there was unfortunately so great a surplus—when broken by percussive action until small enough to pass a sieve rather more than $\frac{1}{8}$ inch in the clear, produced, with Portland cement, a mortar quite equal in strength to that already in use, and having higher degrees of plasticity and water tightness—results undoubtedly due to the circumstance that although the smaller grains of this artificial sand were much finer than those of the river sand, being quite newly broken their ingredient minerals were in no degree decomposed, as is more or less the case with all compound river sands. When mixed in the ratio of one part of the natural sand

*Fig. 8.*




to two of the crushed rock sand, the excellent qualities were still retained, and, as the plant on the ground lent itself to the production of this ratio, it was adopted. It is to be observed that this sand, when wet, had very much the appearance of mud upon a road formed of any bluish macadam. No engineer without convincing proof would believe in its virtues, yet, in conjunction with Portland cement, it makes a mortar nearly equal in strength to that produced from the artificial standard sand of pure crushed quartz, a mortar moreover which properly manipulated is practically watertight, and which has stood the important test of thirteen years, under all conditions of dry and wet treatment, and of water pressure. When this mortar



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came into use, it was no longer necessary to give the stones reciprocating twists on their beds. Even the largest sizes, having bases in some cases of 50 square feet, were so perfectly bedded, by being simultaneously struck near their centres with many two-handed mallets, that such indents as were permitted, extending about 2½ inches, from a plane surface touching the base, were perfectly filled with compressed mortar. It is satisfactory to know that, since its successful employment on the Vyrnwy works, the use of crushed rock, as a material for mortar and concrete making, has much increased both in Great Britain and abroad; but the Author fears that some of the mills in use produce far too much dust. Sand, such as that produced by percussive action (which is the best), cannot be produced by rollers, though stamps or jaw crushers with elevators to return the coarse particles, answer very well.

The quarries are about 1 mile from the dam, and at such an altitude that a gradient of about 1 in 30 was obtained for a double line of 3-foot gauge railway worked by locomotives. A small reservoir was constructed about 1 mile above the quarry on the Afon-y-ddolaugwynion, from which a large volume of water under a pressure (at the quarry) of 140 feet was rendered available. Hydrants were provided; and every stone, from the largest used for building to the smallest sent to the crushers for concrete or mortar, was washed with jets under this pressure, and, wherever necessary, scrubbed at the same time with steel brushes by men in waterproof overalls. The stone was dressed at the quarry; and all stones that could not be lifted by one man were provided with dog-holes for crane-clips, and were carefully balanced with their beds level. The weighing bridge was on the main down line and below the point at which the crushed rock sand, washed river sand and broken stone for concrete, joined it. Thus (the cement being weighed on discharge from the cement shed) the weight of all materials destined for use from day to day was recorded and compared with the monthly measurements. The specific gravity of the dam, 2·595, when dry is, therefore, known with great accuracy.

The quarry railway passed along the inner face of the dam, and the stones were transferred from the wagons by means of specially constructed travelling cranes. The wheel-base of these cranes was 12 feet, the gauge 10 feet, and the radius 30 feet. Each crane was provided with levelling screws and stood level, at a gradient of about 1 in 10, on rails fixed to a heavy timber platform. When a crane had finished the work within range, it set at the same gradient a second platform on to which it then travelled,

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and thus, in attaining successive new positions, it mounted a gradient of about 1 in 10 from the base to the superstructure of the dam. As a rule the stones were bedded as received, but large timber platforms, capable of being moved by the cranes, were maintained in convenient places for the deposit of temporarily unsuitable stones and for broken stone to be rammed into the joints with the mortar.

*Preparation of the Rock Foundation.*—As already stated, all dislocated rock was removed. Where long steep slopes occurred in the sound rock it was benched, but with obtuse inner angles, and it was then rendered scrupulously clean with wire brushes and jets of water under pressure.

*Mode of Building.*—The mode of building was as follows:—Over the irregular surface of the foundation rock thus prepared a good coating of Portland cement mortar was brushed. Upon this the work was raised, in hollow places too small for large stones, with hand-set stones and strong mortar, and only differed from ordinary rubble work in the greater density of its beds and joints. This greater density was secured by permitting neither masons, bricklayers, nor trowels to appear upon any part of the work except the face, and by substituting for them men not too old or prejudiced to learn, with shovels, mallets, and numerous ramming tools of different sizes and shapes. Wherever spaces were too small for good-sized rubble work they were filled with mortar into which macadam-sized broken stone was rammed, but no previously mixed concrete was used. When a sufficiently large area had thus been secured it was levelled up with mortar, among which broken stone was uniformly scattered from shovels, and beaten in with a flat beater formed of $\frac{1}{4}$-inch wrought-iron plate about 1 foot square, turned up $\frac{3}{4}$ inch at each side, and having a wooden spade-like handle inserted in a wrought-iron socket riveted to the centre of the upper side of the plate. The work was thus brought to a perfectly level surface on to which a bed of mortar about 2 inches thick was immediately shovelled, levelled with steel brushes, and, if it appeared unduly stiff, beaten with the same flat beater. Upon this a large stone was lowered and beaten down with many heavy two-handed mallets having cylindrical timber heads 6 inches to 7 inches in diameter and 14 inches long. The effect was to squeeze out some mortar, even from under the largest stones, and to cause it to mount in the joints to a head of several inches. Into these joints mortar and broken stone was packed as before, and if the day's work was nearly completed the higher portions of the joints were



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then crammed with guano bags so completely that to the coming rain, frost or sunshine no artificial work was exposed. It is to be particularly noted that towards the end of a day's work the joints were never allowed to be more than half filled with mortar or concrete, but that the filling so far as it went, was finally finished at the time, by dint of firm ramming with blunt-ended swords and ramming tools, suitable for the various widths of joints. Thus when the work was resumed, whether a single night or many days and nights had intervened, the junction between the new and the old mortar work had the smallest possible area, and had been thoroughly protected from the weather in the interval.

No precaution likely to increase the density or water-tightness of the work was neglected. Even in an ordinary retaining-wall of Portland cement concrete, the signs of bygone Sundays and Bank Holidays are apparent, and moisture passes with comparative facility through the places where they occur. These weak places, caused by the temporary cessation of work, cannot be entirely avoided, but their importance can be greatly reduced by thorough protection of the work from extremes of temperature and from rainfall, and by the proper elimination of unslaked free lime from the cement. For this reason a very large stock of old guano or sugar bags and tarpaulins was always at hand, with which all recent work was thoroughly protected when not being actually built upon.

On the resumption of work, at the place already described, the guano bags were removed and the same process was followed as in the hollows of the rock, until platforms of mortar for bedding medium stones, and later, at various levels, for great stones could be secured. In order to leave abundant space for efficient consolidation no crane-set stone was permitted to come within 1 inch of another.

*Tying into End Rock.*—The builders of masonry dams across steep gorges in the past appear to have lost sight of the analogy between the practice of tying such masonry into a steep face of rock, and that of building the wall of a new house into the toothed edges of brickwork projecting from an old one—a practice of which every builder knows the usual result. The consequence is that in most such masonry dams the junction with the rock, or the masonry near the rock, is fractured, and leakage occurs at the ends of the dam, if not elsewhere. In the process of building a masonry dam each stone is set freely against, and cemented to the end rock. At the time, it is subject to no compression from other loads, but when the weight of the superincumbent masonry comes upon it, that stone and others at the same level are subjected to a shearing

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stress. The stones not held up by the end rock take the compressive strains for which they are built; those held up by the end rock take shearing strains—for which they are ill-suited—arising not only from their own weight, but from the down-pull of the masonry farther from the rock. Even a junction of puddled clay tied into the most carefully made grooves in vertical faces of rock, or the clay itself near the junction, will sometimes leak from precisely the same action and with still more serious consequences. In the case of the Vyrnwy dam the rock, even on the northern side of the valley, is not sufficiently steep to make it necessary to adopt any special precautions—shearing stresses there undoubtedly are, but the strains they produce are such as the masonry will safely bear. In certain other cases, however, the Author has considered it necessary to design an asphalte key similar to, but on a much larger scale than that he used in the culverts, described later, of the Vyrnwy dam, and he has no doubt that this will ensure a perfectly water-tight joint for all time.

*Face Work.*—The face stones were bedded like the hearting stones, except that on the water face the joints and beds were left unfilled for a distance from the face of about 6 inches at the base and 3 inches at the sill of the dam, the mortar bed being held up by means of pads of loose canvas covering iron plates each about 16 inches by 2½ inches by ¼ inch. In order to facilitate the subsequent removal of these pads from between the stones, the ends of the plates were cut at angles of 45° with the sides, and could thus be easily caught with hooked irons. In suitable weather, when the mortar had fairly set and a further course or two of stones had been laid, these packings were removed, and the space was caulked to within an inch of the pitch line with Portland-cement mortar and sand in the ratio of 1 to 1. This mortar was gauged with so little water that it appeared dry. It was caulked with iron rammers as fed from little hanging trays, and the caulking was continued until the surface became damp. If such joints are well set back from the face no frost can injure them, "spelching" from diminished resistance to compression near the edges is avoided—as by a deep chamfer in ashlar masonry—and expansion and contraction of the rock faces of the stones can take place with greatly diminished risk of disintegration in the long course of time for which such a work is or ought to be predestined. In the outer joints of the masonry the ordinary mortar was similarly caulked. The faces of the stones were generally left precisely as they came from the quarry, the rock face, in the larger cases, projecting about 18 inches. Such projections—like the setting back of joints—are

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undoubtedly an important protection against the strains which produce the disintegrating effect of time. The pendulum seismograph near the centre of the drainage tunnel, already described in the Proceedings,[1] shows the dam to be in a perpetual state of motion due to changes of air temperature, and the increased compression near the surface of the masonry when subjected to sunshine is very considerable. All such strains are greatly moderated by the projections of the stones beyond the mortar of the joints.

*General Features.*—On the north side of the valley the masonry is tied into the rock to above high-water level. On the south side, as shown in Fig. 5, Plate 4, it is tied into the rock to a distance of 150 feet in a horizontal direction from the surface of the slope of the valley, and 35 feet measured vertically from the top water level. Beyond and above that point the rock rises slowly and is covered with impermeable glacial clay. The precaution was taken, however, of cutting a trench through this clay and into sound rock, and refilling it with clay-puddle. Against the face of the dam, throughout its length and from rock to ground level, a puddle-wall was put in; but subsequent experience of the water-tightness of the masonry, shows this to have been an unnecessary precaution.

The carriage way required by the Act of Parliament to be made round the valley is carried over the sill of the dam by thirty-one masonry arches of 24 feet span. The nineteen central arches form the principal overflow, and provide a waste weir 456 feet in length, for a drainage area—when the Afon Cowny and Marchnant are connected with the lake—of 23,000 acres to 24,000 acres, or about 52 acres to each foot of overflow.

The side arches have higher sills than the central arches, and the little overflow through them is collected by masonry channels constructed on the outer face of the dam at or near the original slopes of the valley, as shown in Fig. 5, Plate 4.

*Discharge-Culverts.*—In Figs. 4 and 5, Plate 4, the southern valve-tower and discharge-culvert are shown. The northern valve-tower and discharge culvert are similarly situated towards the northern end of the dam. These culverts are 15 feet in diameter and of Staffordshire blue brickwork in Portland-cement mortar. During the construction of the masonry above their level they were used to pass the river water, and were subsequently closed, first, by reducing the diameter to 12 feet with four rings of brickwork,

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 117.

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and finally by filling in with horizontal brickwork. The upper beds of the horizontal brickwork under the new circular work, and of the new circular work under the original circular work of the culvert, were caulked with nearly dry mortar.

When an ordinary discharge tunnel through rock or earth is stopped with brickwork, there is no risk of leakage due to distortion of the figure of the tunnel after the insertion of the horizontal work, but the case of a large culvert through a masonry dam is very different. Here, as the masonry proceeds, and the weight comes upon it, the culvert (together with the work immediately over it) is strained, and the vertical axis is shortened. Into this slightly oval form the brickwork stopping is built, but necessarily without the strain previously produced in the circular work. When water rises in the reservoir the vertical stress common to the masonry and to the original circular work near the face of the dam is largely if not wholly removed, and the crown of the culvert seeks to rise and thus to part from the brickwork stopping. In the case of the Vyrnwy culverts the strain from the circular form was quite sensible; and although, owing to the general dimensions of the work, the removal of that strain might not have caused leakage, all doubt was set aside by a key of asphalt. This key was a collar 4½ inches thick and 2 feet 6 inches wide, formed in a cavity made by the omission of 2 feet in length of the external rings of the above-mentioned four rings inserted as part of the stopping near the face of the culvert. It is shown in section at Fig 4, Plate 4. From the highest part of this annular space an inlet funnel was built about 3 feet 9 inches higher, and into this, heavy tar oil, nearly boiling, was poured and allowed to flow through small holes at the lower ends of the collar. When the brickwork had thus been well heated hot asphalt was substituted, which was also allowed to run through for a short time and was then sealed up with brickwork. This asphalt was brought to such a condition with tar oil that, at ordinary temperatures, it would flow slightly but sensibly in a week or two. The intrusive water pressure, if any, would tend to tighten such a joint, and even in the case of a reservoir frequently filled and emptied it would no doubt remain watertight.

*Compensation Water and Discharge Valves.*—The southern culvert contains two discharge pipes, of which the smaller one, 18 inches in diameter, supplies what is described in the Act of Parliament as the "daily compensation" water to the river, viz., a uniform flow of 10,000,000 gallons during every day of the year. The larger pipe, 30 inches in diameter, supplies the

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"monthly compensation," being an addition to the "daily compensation" of 40,000,000 gallons a day during four successive days in each of the eight months from February to October, inclusive. The effect of this large volume of "monthly compensation" water is insignificant, except in the River Vyrnwy. To the Severn it is useless, and any trifling advantage to the smaller river is certainly not commensurate with the enormous cost of providing it. The daily compensation pipe passes to a still-water basin, 8 feet wide, and having a depth of 3 feet of water, in a building shown by dotted lines on Fig. 5, Plate 4. This basin is 22 feet long. Beyond the end most distant from the gauge there is a covered concrete chamber, into which the 18-inch daily compensation pipe discharges. This chamber again discharges through four vertical plates 1 foot 9 inches apart, perforated with holes ranging from 1 inch in diameter in the first screen to 1½ inches in diameter in the last screen, and the head lost at each screen is 20½ inches, 5½ inches, 3 inches and 3 inches respectively. With less loss of head than this 32 inches, it was found in practice that still water at the notch could not, on this principle, be attained. In subsequent works, where orifices or notches giving complete contraction have been employed, the Author has avoided the use of screens by constructing an approach channel to the rectangular still-water basin, having slow ogee-shaped curves from the inlet pipe to the full size of the rectangular basin. This basin has, at the gauge-plate, the full section required for complete contraction of the vein, and has a length equal to not less than one and a half times its width. The length of the ogee portion must depend upon the velocity of water in the supply pipe, but it should not be less than four times the length of the rectangular basin. The discharge of 10,000,000 gallons a day takes place through a sharp-edged rectangular orifice, precisely 12 inches deep and 37·438 inches wide, in a vertical plate. The level of still water is adjusted to a vertical point projecting upwards exactly 11·904 inches above the upper edge of the notch, and the lower edge is 12 inches above the bottom of the basin. The determination of the length of the notch was made by measurement after the point-gauge had been fixed, and the Author believes that it contains no sensible error. There are slight eddies visible on the surface of the water just over the orifice, and the co-efficient of discharge is therefore slightly less than it would be if the depth above the orifice were a few inches greater. Below the gauge is a masonry and concrete basin having a capacity of 22,000 gallons, the level of the water in which may be very

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accurately determined by a hook-gauge and vernier. By means of an apparatus differing considerably from anything of the kind previously used, the whole of the flow from the notch can be almost instantly diverted to the measuring basin, and as quickly returned to the ordinary channel. The apparatus works perfectly, but it is never used. The whole arrangement, including the large measuring basin, is a scientific and very costly pint-pot sort of measurement, and was destined to satisfy one of those expensive and useless conditions which, at the instance of a parliamentary opposition, sometimes find their way into Acts of Parliament. It is lamentable that, in such cases, a determination once made, with any desired degree of accuracy, concerning the discharge of water through a clean orifice of constant figure, should not be understood by all concerned to be unchangeable. The Author's contempt in this case for the object of his own work leads him to omit all detailed information on the subject. In the section, Fig. 4, Plate 4, is shown the monthly compensation gauge-basin, where four orifices, each exactly similar to that above described, are provided for the measurement of the monthly compensation water. Here is, in effect, the paradoxical admission that five equal orifices under equal heads will discharge equal volumes and will continue to do so, though one of them cannot be trusted to do so! The vertical inlet-pipe, with a horizontal bell-mouth, is added merely to comply with another statutory condition that the compensation water shall not be supplied from below a certain level, though at the northern culvert any quantity of water may be discharged from any level! The valves are worked by ordinary crank handles from the valve chamber. The northern valve-tower and discharge culvert are similar to the southern. The culvert contains a 39-inch discharge-pipe without a raised inlet, and in the valve-chamber, besides the valve-gear, there is a level recorder worked by a float in a copper tube passing from above the top water level to the lake bottom.

*The Mortar and Concrete.*—Except in hydraulic works, it is rarely possible to secure an exact test on a large scale of the results of mortar and concrete making. When an experienced man makes mortar into little briquettes to be tested for strength, or rams it into the end of a pipe to be tested for water-tightness, the heavy sense of individual responsibility and the pleasant sense of rivalry induce him to do his best to obtain the highest possible result. He mixes it apparently almost dry, and he rams it until it has assumed the condition of a dense incompressible jelly, just visibly damp at the surface. But when a gang of men or a sub-con-

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tractor are put to obtain the same result on a large scale, the sense of responsibility is too divided, the sense of rivalry too distant, and the sense of economy of labour too distinct to permit them to reject the apparently useful services of an excess of water. Instead of consolidating the concrete or mortar they at once fill its interstices with incompressible water, thus saving the labour of ramming—which on such a material is quite useless—and leaving a porous mass of comparatively little density. Where such a custom prevails, well may speakers at the Institution of Civil Engineers assert, as they have asserted in the past, that concrete cannot be made watertight. The Vyrnwy masonry dam is, the Author believes, absolutely watertight for the 15 feet or 20 feet of its thickness nearest to the water. The mortar and concrete were put in so dry, that considerable ramming was everywhere necessary to produce the jelly-like consistency which betokens incompressibility, and until that consistency was everywhere attained, ramming did not cease. It may be that the Vyrnwy dam, having concrete only in the joints of its masonry, is not a fair test. Another work, however, wholly of concrete, still more strongly supports this view. For reasons to be explained later, it was desired to construct a permanent culvert 767 yards in length, and 4 feet 6 inches in internal diameter through open gravel, at a level of 56 feet below the lake. When subjected to this external pressure it was important that the culvert should be practically watertight. To internal pressure—in excess of the external pressure—it never could be subjected. With the experience he had had, both on a large and small scale, of the watertightness of properly made concrete, the Author had no hesitation in constructing this culvert, as shown at *Fig. 9*. It is circular, with a thickness of only 18 inches, which is abundant for strength. With the head of 56 feet the pressure, tending to crush the concrete, would be about 3·7 tons, and including the gravel where deep, possibly 4 tons per square foot, while the concrete—6 of gravel and broken stone to 1 of Portland cement—would crush at between 200 tons and 300 tons per square foot. This pressure, 4 tons per square foot, is insignificant when compared with the pressure put upon brickwork rings in some colliery shafts. A length of 62 yards of the Vyrnwy culvert next to the Hirnant Tunnel, was built with the same thickness, 18 inches, of Staffordshire blue bricks in cement mortar; but the remaining length of 705 yards, consisting of moderate curves and straight portions, was built, either as shown at *Fig. 9*, or similarly to it, but without the 4½-inch thickness of brickwork at the base, which was merely used to protect the

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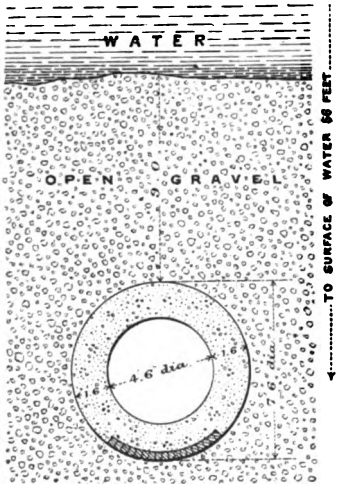
concrete in bad and wet ground. This culvert was constructed with both invert and arch centres of wrought iron, and the concrete was put in even drier than in the case of the dam, but was rammed continuously until it shook like a jelly. Exceptional care was also taken with the brickwork portions, from which, however, several needle-like veins of water broke out—always in the end joints, not the beds—when the pressure came upon it. These were subsequently stopped, under the directions of Mr. Joseph Parry, M. Inst. C.E., by injections of Portland cement, under pressure from compressed-gas cylinders. The concrete portion is practically watertight. There are only three visible leakages, amounting in the aggregate to 4¼ pints per minute. As the internal area of this portion is 3,320 square yards, and the external area 5,530 square yards, the whole flow does not exceed the rate of one gallon a minute through 6,260 square yards of internal, and 10,400 square yards of external area. The total length of joint, that is to say, of surface at which new concrete was connected with concrete already set, was about 1 mile. Here then is a thickness of 18 inches of 6 to 1 concrete practically watertight, under a head of 56 feet. Such a result would certainly not be obtained from concrete as usually made. These facts and numerous exact experiments in connection with the production of watertight concrete justify the Author in stating, as a fact ascertained beyond all question, that no fear need be entertained of too little water being used, if only by repeated ramming the incompressible condition of a jelly can be produced. The rubbing of the fine portions of lime or cement or sand into the interstices of the coarser particles during the shaking and subsequent trembling of the whole mass under the rammer cannot, the Author believes, be attained in any other way. There is no better or simpler test than to compare the specific gravity of the concrete so prepared with that of the rock from which the bulk of its constituents are obtained.

*Fig. 9.*




Scale, ½ inch = 1 foot.

CROSS-SECTION OF CULVERT.

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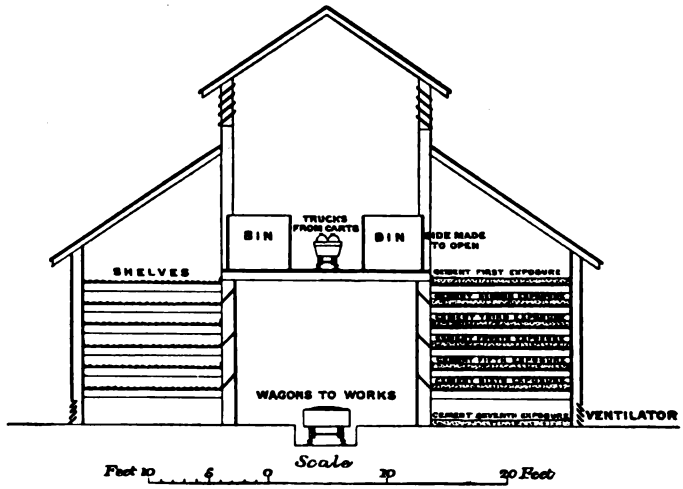
Much of the successful construction of watertight concrete was due to the great care taken with the cement; 90 per cent. was required to be capable of passing through a sieve of sixty brass wires to the lineal inch, weighing $3\frac{3}{4}$ ounces per square foot. For the first few months of the work the tensile strength was required to be such that of six briquettes, eight days after being moulded, kept in water from the second to the seventh day, at least one would sustain without fracture a weight of 4 cwts. per square inch for not less than one hour, but the results actually obtained were so much higher than this that from February, 1883, the tensile test was increased to 5 cwts. sustained for one hour. More than

*Fig. 10.*




CEMENT WAREHOUSE.

9,000 briquettes were tested to determine and maintain the strength of the cement employed, and the average result was $6\frac{1}{3}$ cwts. per square inch.

But much more important than the actual strength of the cement after a few days, is the condition in which it is used. The manufacturers do not profess to store it in such a manner as to reduce the free lime, to the presence of which the cracks so common in ordinary concrete work are largely due. Turning over a considerable depth of cement on a floor is a most inefficient method. Parts of the cement are thus over-exposed, and others under-exposed, and if different samples of the bulk are tested it will be found that they differ widely in respect of the presence of unslaked free lime. To

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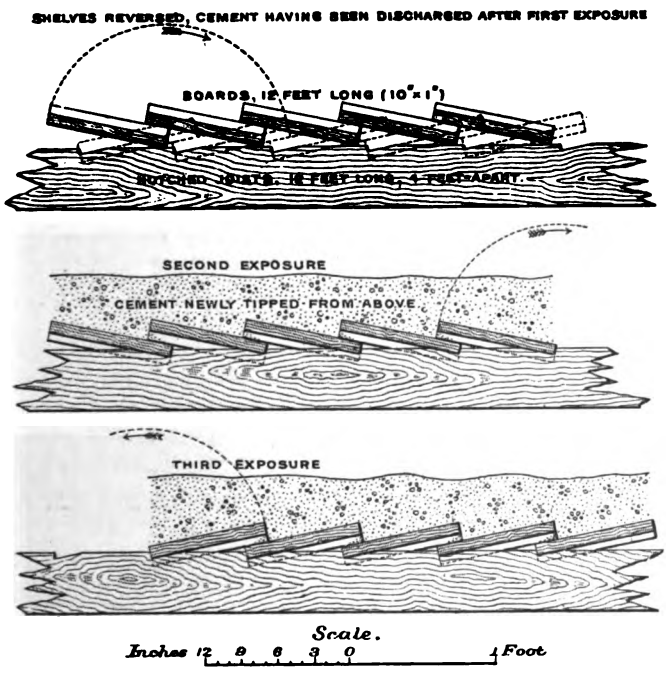
improve the uniformity of the process, and to ensure a systematic and economical exposure of all parts to the air, the device illustrated at *Fig. 10* was adopted. Most of the area of the cement warehouse was occupied by six tiers of shelves 2 feet apart, consisting of 10-inch boards, shown on a larger scale at *Fig. 11*, lying loosely across timber joists and stiffened with cross battens. On the upper floor between the shelves was a high-level narrow-gauge tramway, upon which the sacks of cement were brought in on trucks. From the trucks the cement was discharged into bins,

*Figs. 11.*


SHELVES REVERSED, CEMENT HAVING BEEN DISCHARGED AFTER FIRST EXPOSURE
BOARDS, 12 FEET LONG (10" × 1")
SECOND EXPOSURE
CEMENT NEWLY TIPPED FROM ABOVE
THIRD EXPOSURE
Scale.
Inches 12 9 6 3 0 1 Foot

and from these it was shovelled through side openings over the upper tier of loose boards to a thickness of 3 inches or 6 inches. One or two days later two men passed respectively along the two ends of each set of boards, shown in *Fig. 11*, and tipped them up one by one. The cement then lay very lightly on the next lower tier, from which it was similarly tipped to the next, arriving on the lowest floor after six very complete turnings and continuous exposure in thin layers during one to three or more weeks as might be found desirable. The warehouse was 107 feet long by

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43 feet wide, and would contain, at 6 inches thick, 350 tons of cement, besides a stock of 200 tons in the bins.

It was required that the cement as delivered should be slow-setting. In the earliest stages of the work the condition of such cement as regards the presence of free or loosely combined lime was determined by the old method of making thin pats and observing the degree of tendency to crack after many days; but this was subsequently abandoned for a perfectly simple and exhaustive test which could be made in a few minutes, and which the Author has adopted ever since. A hand sample of cement, a small vessel of water, a marmalade pot and a thermometer are left together for a short time to acquire a uniform temperature. The cement is then gauged in the pot as quickly as possible, with just sufficient water to render it plastic; and the thermometer being immediately pressed into it, the initial pressure is recorded. If within fifteen minutes the rise of the thermometer exceeds 2° F., or within sixty minutes 3° F., the cement is further exposed before use. No bin of cement was certified for use on the works until it had passed one of these tests. This precaution, combined possibly with the comparatively dry method of manipulation already described, is so effective that where it has been adopted the Author has never seen a hair crack of the kind so familiar where fresh cement is used.

During the progress of the building the actual mortar used was regularly tested in tension, and 9-inch cubes were made and preserved of both the mortar and concrete collected from the work. Large numbers of these have been crushed by Professor W. C. Unwin and Mr. D. Kirkaldy. The lowest result obtained was from a block of the concrete a little more than three months old, which gave 84·23 tons per square foot: the highest was from a block of the concrete three years old, which bore 298·6 tons per square foot before cracking. The mean resistance to cracking under compression of all the blocks tested between two and three years after moulding was 215·6 tons. This was satisfactory, but still more so was the circumstance that blocks of concrete cut out of the hearting of the actual work, at different depths and therefore of different ages, from a well sunk below the drainage tunnel, gave still higher results. The lowest resistance to cracking under compression was 184·4 tons per square foot obtained from a block about nineteen months old; the highest was 329·5 tons per square foot, obtained from a block two years old, and the mean of nineteen blocks between one and two years old was 263 tons per square foot. Examples of the concrete excavated from this well are laid on the table. The specific gravity of this concrete when dry varies from

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2·48 to 2·55, or from 155 lbs. to 159 lbs. per cubic foot, a very remarkable result, entirely due to the comparative absence of vacuities which the polished surfaces clearly show. The complete adhesion between the mortar and the stones is also shown by the fact that specimens of this concrete have been ground down to slabs less than $\frac{3}{16}$ inch thick. The rough side of No. 1 specimen is part of the side of the rectangular well, and shows the tool marks of the excavator passing through stones and mortar alike. Blocks for testing were cut from the side of the well and sawn into a rectangular figure. The well-side slab No. 1 when sawn off was polished on the inner side. It is from 1 inch to $\frac{1}{4}$ inch thick, has an area of about 50 square inches, and has been subjected to the rough processes of rock excavation. The adhesion of the stones to the mortar in this concrete was also very clearly shown by the fact that in the process of breaking by crushing, the fractures very generally passed through the stones and not over their surfaces.

## The Vyrnwy Aqueduct.

As the Vyrnwy Valley trends towards the south and the water was wanted in the north, a lateral outlet from the lake, not passing through the dam, was found desirable. Such an outlet was secured by a tunnel known as the Hirnant Tunnel, 2¼ miles in length, to connect the valley of the Vyrnwy with the parallel valley of the Tanat 5 miles farther north. By this route only two other tunnels, the Cynynion and the Llanforda—each less than a mile in length—were required before the aqueduct reached the Welsh border. Near Oswestry the aqueduct crosses from Wales to England, and here the general level falls—though it is kept nearly on the watershed between the basins of the Dee to the north and the Severn to the south—until the basins of the Weaver and Mersey are approached. Thus the greater part of the aqueduct passes along the highest available ground. The iron portion of the aqueduct will ultimately consist of three lines of pipes, each capable of delivering about one-third of the total available supply when the water from the Afon Cowny and Marchnant drainage areas has been added to the supply from the area draining direct to the lake. The pipes have hitherto been completed for the first instalment of water only, but the works generally—with the exception of three balancing reservoirs for the second instalment, two for the third, additional filter beds, and two tunnels to divert the Afon Cowny and Marchnant waters to the lake—have been completed for the full supply of at least 40,000,000 gallons a day.

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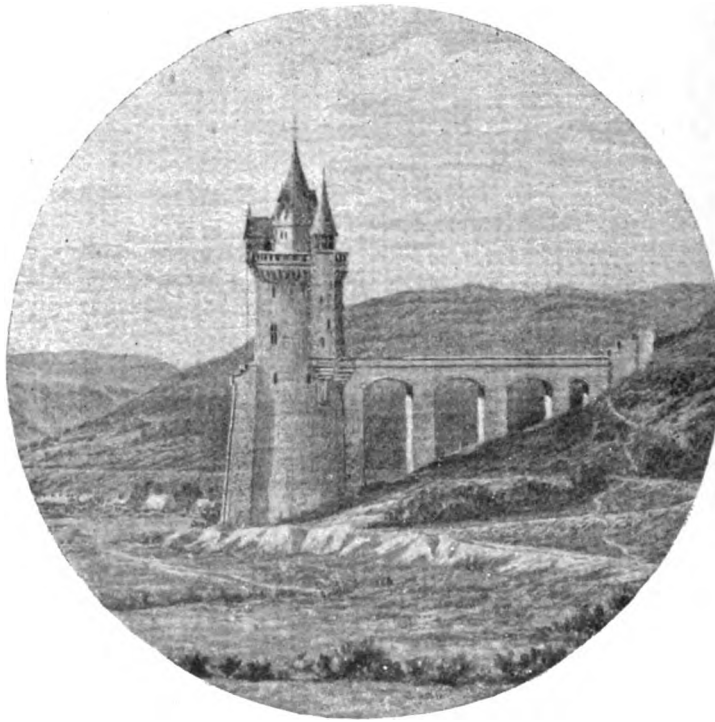
*The Vyrnwy Tower.*—The invert at the inlet end of the Hirnant tunnel is 57 feet below the overflow level of the lake and beneath the valley of a considerable stream, the waters of which are much more peaty than the average of other streams flowing into the lake. To avoid the flood waters from this and other streams, and to secure deep lake water, a place for the inlet to the aqueduct was chosen off a promontory about 730 yards north-west of the inlet to

*Fig. 12.*



THE VYRNWY TOWER.

the Hirnant tunnel. Here was built the Vyrnwy tower, shown in *Fig. 12*, and in section at Fig. 13, Plate 5. The height from the base is about 170 feet, of which only 110 feet appears above the top water level. The perspective view represents the tower before impounding began. This structure is wholly of concrete, of the kind already described—faced externally in the process of building with "sneck faced" rubble masonry. The circular work was built,

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between inner segments of wrought-iron plates—bolted together through angle-irons, into a complete ring 30 feet 6 inches diameter —and outer laggings of timber held up by hoops of wrought-iron encircling the tower. The centerings were smeared with soft soap before being used. The concrete was put in comparatively dry, and rammed into the jelly condition. On the removal of the centerings this concrete was found so perfect that no rendering or further work was necessary. Round the springings of the cupola beneath the gallery, an annular recess was left in the thickness of the concrete within which, upon occasional cast-iron chairs about 9 inches apart, plough steel wire was wound, from a specially designed machine which secured uniform strain. During the winding this wire was smeared with asphalt, with which also the annular recess was subsequently filled.

To secure the purest water it is important that the inlet-valves to the tower should draw only from a small depth below the surface, whatever the absolute level of the lake. Two inlet-valves shown in elevation at AA, Fig. 13, and in sectional plan at A, Fig. 14, and dotted in plan at A, Fig. 15, Plate 5, are provided. Each consists of six 9-foot lengths of steel tube with gun-metal faced ends. These steel tubes, resting end on end, form a continuous standpipe from the lowest available water-level to above the highest flood-level, so that the water-pressure does not tend either to close or open, or to resist the closing or opening of any of the joints. They are protected by side walls and a grating, as indicated in the figure. Each tube is guided near either end at three points of its circumference, and internally each is provided in horizontal planes near its upper and lower ends respectively with three equidistant gun-metal snugs or brackets. In the axis of each stand-pipe is a steel shaft having upon it, at six equidistant levels, a set of three radial arms, one of which sets may be engaged with the three brackets attached to any one of the six lengths of tubes by simply turning the central shaft by means of a light crank handle B, Fig. 15, Plate 5, until the pointer of the corresponding dial C, indicates that the correct position has been reached. In this position all the other arms are free. From the upper end of each of such central shafts, a chain passes over a wheel, of which one is shown on Fig. 13, to a hydraulic ram, by which the whole of the tubes above the joint which it is desired to open are readily lifted or lowered. The arrangement works well, and the valves are quite tight when closed. Within the tower where the water is strained, the level—when water is passing along the aqueduct—is substantially the same as in the lake; and in



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order that the water surrounding the strainers may be as quiescent as possible, the incoming water is caused to pass through similar tubes DD, up the inside of the tower. These inner tubes may be raised and lowered in precisely the same manner as the outer tubes, to suit the varying level of the water. Thus the lower part of the tower has considerable action as a depositing tank, and the foul water is from time to time ejected by a very efficient jet-pump, worked by a head of about 150 feet.

Before it enters the aqueduct, the water is passed through three cylindrical strainers of a type not previously used, Figs. 13 and 14, and three closed channels, two of which are shown below the strainers. Each strainer is of fine copper wire gauze stretched over a cylindrical frame of wrought iron 25 feet high and 9 feet diameter. It carries a ring of india-rubber at its lower end, and this rests freely upon a bell-mouthed casting forming the upper end of a vertical cast-iron pipe, 46 inches diameter, containing at K, Fig. 13, Plate 5, an ordinary throttle valve by which the flow through the corresponding strainer may be at once cut off. The head between the water without and within the strainer never exceeds $1\frac{1}{4}$ inches. When, as originally constructed, $1\frac{1}{2}$ inches was approached, the fact was indicated by the lifting of a piston, about 24 inches diameter, in an immersed cylinder, the lower end of which is open to the water without, and the upper end to the water within the strainer. A little leakage was permitted to take place past the piston, and a wire passing over a pulley to a counterbalance weight above the water, gave the means of adjustment of weights, and of ascertaining whether the intended maximum loss of head had, or had not, been attained. In practice, however, it was found that the full quantity, 10,000,000 gallons to 15,000,000 gallons a day, liable to be passed through a single strainer, made it desirable to cleanse that strainer once in twenty-four hours; the indicator in its first form is, therefore, not now required.[1]

Each strainer has three equidistant vertical guides between which, when it requires cleansing, it is lifted by means of the chain of a four-ply hydraulic ram of 16 feet stroke vertically over it, and enters one of the sheet-iron casings on the washing floor above. Within each of the strainers, there are four vertical 3-inch copper

[1] Mr. Joseph Parry, M. Inst. C.E., who now has charge of the works, proposes to allow the counterbalance weight to dip into a bath of mercury, or otherwise to add an increasing resistance to its descent, and thus to cause the piston to occupy different positions in the cylinder corresponding with the different degrees of "loss of head." The position of the counterbalance weight may thus be caused to indicate the precise loss at every instant.

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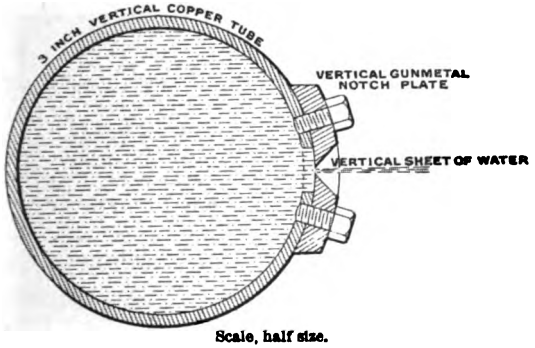
pipes connected radially at their upper ends, capable of revolving in a horizontal plane, in a bearing and footstep carried by the strainer frame. These are shown in plan at the right-hand strainer, Fig. 14, Plate 5, and in the elevation, with the strainer in position for washing, above the washing floor, on Fig. 13. Each pipe is provided with twenty-one sharp-edged vertical slots in one straight line—mere slits, each 7 inches long and $\frac{1}{32}$ inch wide—formed in section, as at *Fig. 16*. The slots are 6 inches apart vertically, and those in the two opposite radii are level with the spaces in the two intermediate pipes, so that when water is turned on and the four pipes are caused to revolve, the wire gauze is swept by two complete vertical sheets of water made up of 84 sheets, each 7 inches deep in four radial planes. Each slot is so formed that the contraction of the vein of water is wholly outside

*Fig. 16.*




Scale, half size.

SECTIONAL PLAN OF VERTICAL PIPES IN WASHING TURBINE.

the pipe, and the result is a thin unbroken vein. Each pipe may, for the purpose of adjustment, be turned upon its vertical axis, and the vertical veins, having been thus brought to small angles with the radii of the strainers, cause, when charged with water under pressure, rotation of the pipes and their framework within the strainers after the manner of a reaction turbine.

The inlet to this washing turbine is at the top, in the vertical axis of the strainer, and is shown at Fig. 13, Plate 5, and enlarged at Fig. 17. When the strainer, with its washing turbine, has reached its full height within the casing, a port in the side of this inlet pipe is brought opposite to the pipe supplying water from a tank on the neighbouring hill about 115 feet above the tower. Before water is turned on in the direction of the arrow, the joint is only between the planed surfaces of the vertical cast-



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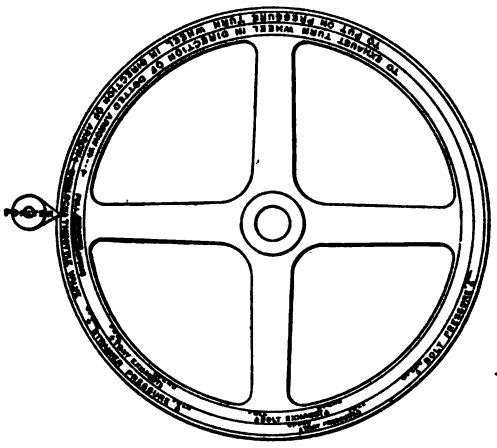
iron pipe and the gun-metal cover of the india-rubber; but the instant the pressure is applied, the india-rubber closes on the faced surface of the pipe and makes a perfectly watertight connection. In order to prevent the unstrained water from entering the strainers through the port in the inlet pipe, the piston, shown in the lower part of Fig. 17, is kept by its own weight normally below that port, but, being connected with the chain of the hydraulic lift, is raised above the port in the process of lifting the strainer. The next stage is to close the bottoms of the casings, and to form an outlet for foul water produced by the washing. This is effected by means of the hinged wrought-iron trays, shown at GG, Fig. 13, Plate 5, which are drawn up beneath the

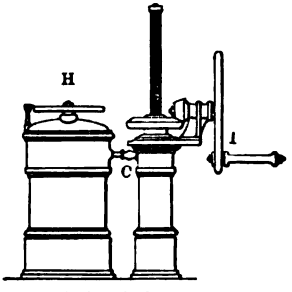
*Fig. 18.*



Scale, one-eighth full size.

PLAN OF WHEEL AT H, *Fig. 19.*

*Fig. 19.*




Scale, ½ inch = 1 foot.

casings by separate chains, and hydraulic rams. In this position they discharge the whole of the washing water into the trough surrounding the inside of the tower as shown just below the washing floor on Fig. 13, whence it passes into a line of pipes which carries it to the lake on the down-stream side of the tower.

The actual process of washing is very short, and, excepting the turning on and off of the washing water, is effected by merely turning the light horizontal wheel, H, *Figs. 18* and *19* (shown in position in Fig. 15, Plate 5), in reference to the fixed pointer at its edge. Below this wheel, locking-gear is provided which renders it impossible for any action to take place in wrong order. Thus a boy can perform all the operations without danger or difficulty.

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When a strainer is to be washed the process is as follows:—

(1) To close the throttle valve K, Fig. 13, Plate 5, in the outlet pipe below the strainer by turning handle I, *Fig. 19*, and Fig. 15, Plate 5. When this valve is closed, and not until then, sliding bar C, *Fig. 19*, is free to move. (The pointer on the wheel H, *Fig. 18*, now stands at "unlock throttle-valve," that being the only position of the wheel in which the throttle-valve can have been opened.)

(2) To slide the bar C to the left, thus unlocking the "strainer pressure."

(3) To turn the wheel till the pointer stands at "strainer pressure," when the hydraulic ram lifts the strainer 61 feet into casing. This unlocks "tray pressure."

(4) To turn the wheel to "tray pressure," when the hydraulic ram lifts the hinged tray to the underside of the casing. This unlocks "bolt pressure."

(5) To turn the wheel to "bolt pressure," when the small ram below the casing (Fig. 13, Plate 5) drives a wedge-bolt horizontally and presses the tray tightly up to the underside of the casing.

(6) To turn the water on to the washers for about three minutes.

(7) To turn the water off.

(8) To turn the wheel to "bolt exhaust," when the bolt holding up the tray is withdrawn and the "tray exhaust" is unlocked.

(9) To turn the wheel to "tray exhaust." This lowers the tray and unlocks "strainer exhaust."

(10) To turn the wheel to "strainer exhaust," when the strainer descends, with the gauze in a quite bright and clean condition, to its seat on the bell mouth. This unlocks the slider bolt C.

(11) To draw the slider bolt C, thus unlocking the crank handle I, and allowing the throttle valve to be opened by means of that handle.

Water from the tank, 115 feet above the tower, supplies the turbine-washers and drives the two-cylinder hydraulic engine, Figs. 13 and 15, Plate 5. The cylinders are 11 inches in diameter and 17 inches stroke, and drive three single-acting ram pumps of 3 inches in diameter and 10 inches stroke, which work the hydraulic rams at a pressure of 600 lbs. to 800 lbs. per square inch.

The Author now reaches one of those phases, experienced by every engineer, in which Nature has asserted her way in opposition to his will. It was not believed that the excellent Vyrnwy water would set up galvanic action between wrought iron and copper, but it did. The first strainers used were of woven wire-gauze, having 14,400 meshes to the square inch. Nothing could be more

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perfect than their action so long as they retained their strength. The suspended impurities settled on the outer surface of the gauze as a thin gelatinous veil mixed with opaque particles, which disappeared into the drain with the first sweep against the interior of the vertical sheets of water from the turbine. At no time did the Author discover any impurity locked in the gauze, which, after being washed, was as bright as when new. In ordinary cases copper was electro-negative to iron, and the iron was decomposed first, but, owing probably to the comparative thinness and to the large surface of copper wire, this action was reversed in the Vyrnwy strainers, and, small though the acidity of the water was, decomposition of the copper rapidly set in. After a few weeks' use this gauze became brittle and useless. If it had been fastened to wooden frames fixed to the wrought iron the difficulty would not have occurred, and it may still be removed by making this change. Strips of zinc hung within the screens and in contact with the copper, by creating an electro-positive which could be replaced, did much to save the gauze, but by making the wires heavier (involving a reduction in the number of meshes to 10,000 per square inch) the life of the gauze was greatly increased, and this is the mesh used at present. The Author has no hesitation in using these fine meshes on wooden frames; they are more easily washed than coarser meshes, in which stringy matter is apt to become entangled, and they are certainly more useful.[1]

*Hirnant Tunnel.*—By means of the concrete culvert already described the water is passed to the inlet end of the Hirnant Tunnel. Here there is a shaft with a valve controlling the supply from the Tower. In the same shaft there is a pipe in communication with a somewhat lower level of the lake by means of which, if it were ever required, a supply to the tunnel might be maintained independently of the tower supply. This tunnel is circular in section, with a minimum diameter of 7 feet. The total length is 3,900 yards, of which 660 yards are lined with brickwork. The invert has a fall of 2·04 feet per mile, and where not lined it is dressed or finished with concrete to a fairly smooth surface; the remainder is left with the irregularities produced by blasting, which were limited by the specification to a distance of 2 feet from a cylinder 7 feet in diameter. The rock was for the most part clay-

[1] Since the above was written the Author has ascertained that Mr. Parry has successfully met the difficulty by placing sheet-copper between the iron and the gauze and in contact with both; the greater mass in relation to its surface of this added copper if it did not create a balance no doubt caused decomposition of the iron rather than of the copper.

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slate, volcanic ash, and quartz. The driving was done by means of compressed air drills.

*Hirnant—Parc Uchaf Siphon.*—At the Hirnant end of the tunnel the water is discharged into an open well, in which the inlets to the three lines of pipes are fixed. From this point the first siphon, consisting of 42-inch pipes, begins. It is 7 miles in length, and terminates at the Parc Uchaf balancing-reservoir. The greatest head (317 feet) occurs at the River Tanat, beneath which the pipes are laid. At the River Rhaiadr the pipes pass down an incline of 0·66 vertical to 1 horizontal, and are anchored to blocks of concrete in the rock. The precaution of anchoring the pipes to resist the outward pressure in case of too sudden stoppage of the water below, was also taken near the top of the slope before they turned down, and at all other points of the aqueduct at which sharp curves occur. South of the Rhaiadr there is a self-closing valve which acts when, owing to a burst or otherwise, the velocity becomes abnormal. In general design it consists of the usual disk of metal held in the waterway perpendicular to the current. The disk is counterbalanced by weights and levers tending to maintain its position against the pressure due to the velocity of the water. When that pressure exceeds the counter-pressure a trigger is liberated, and permits a weight to close a throttle-valve very slowly across the waterway. At all the summits, and on some parts of the falling lengths, there are air-valves, and at all the low points there are 12-inch scour cocks and discharge pipes. The fall of this length is 4·5 feet per mile, and the discharge after the pipes had been laid twelve years has been measured at nearly 15,000,000 gallons a day. This is somewhat less than the discharge of the lower lengths, and there is reason to believe that the true delivery is somewhat greater. The nominal volume for which each line of pipes was designed was 13,000,000 gallons a day.

*Parc Uchaf Reservoir.*—Here the water of each pipe passes into and out of a small open well with which the reservoir is connected. In order to promote circulation in the reservoir there is also a connection with the main above the inlet to the well; but the design does not permit the whole of the water to pass through the reservoir, and this, having regard to recent researches concerning the improvement in open reservoirs of even such excellent water as this, was an obvious mistake of the Author's. It was, however, remedied in other balancing reservoirs. The reservoir already constructed for the first instalment contains 2,000,000 gallons at a depth of 15 feet; and land has been acquired for a similar reservoir for each of the subsequent instalments. The

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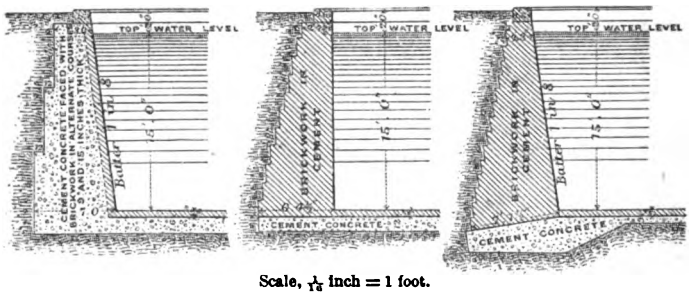
retaining walls of the various balancing reservoirs were varied in construction, according to the class of materials available and the foundations met with in the different localities respectively. Three types are shown in *Figs. 20.*

*Parc Uchaf—Cynynion Siphon.*—The length is 6¼ miles, the diameter of each pipe 42 inches, the maximum head 220 feet, and the fall 4·5 feet per mile. The design is generally similar to the Hirnant-Parc Uchaf length.

*Cynynion Tunnel.*—At the inlet and outlet respectively of this tunnel there is a brickwork well, in general design similar to that shown in plan and section at Fig. 21, Plate 5, to which the triple pipes converge. The fall of the tunnel is 2 feet per mile; the length is about 1,520 yards, and the design is substantially the same as that of the Hirnant Tunnel. It passes mainly through very jointed limestone and shales at the base of the Carboniferous series, and the whole of the invert and most of the arch have been lined with brickwork or concrete.

*Morda Siphon.*—Between the Cynynion and the Llanforda tunnels

*Figs. 20.*




Scale, $\frac{1}{16}$ inch = 1 foot.

TYPES OF RESERVOIR WALLS.

a narrow gorge of the River Morda occurs, across which is the Morda siphon, only 183 yards long, and subject to a head of 80 feet.

*Llanforda Tunnel.*—The inlet is shown at Fig. 21, Plate 5, and has been generally described under the head "Cynynion Tunnel." The length of the Llanforda Tunnel is about 1,640 yards, and the fall, diameter and other features are similar to those of the tunnels already described. The rock passed through consisted chiefly of limestones and sandstones of the Carboniferous series. The whole of the invert and 673 yards of the arch have been lined with brickwork or concrete.

*Oswestry Reservoir.*—At the outlet of the Llanforda Tunnel, a

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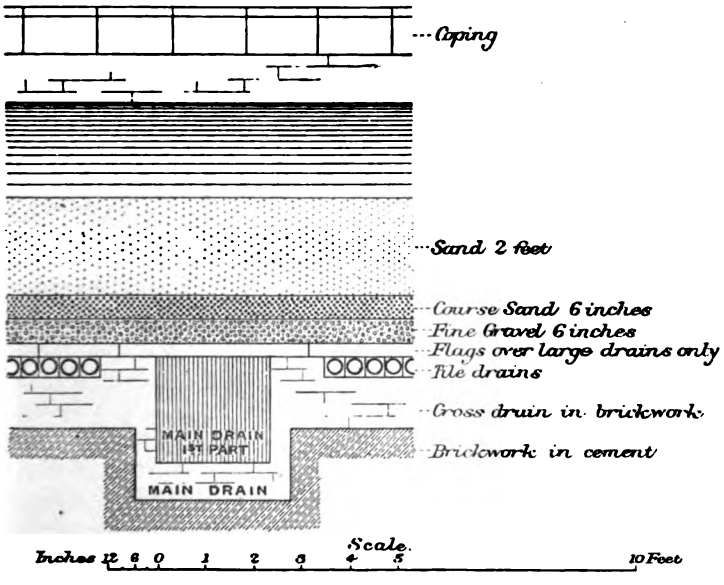
natural basin offered a favourable site for a balancing reservoir of 46,112,000 gallons. The dam is of the ordinary British earth-work construction and about 510 yards long. The puddle-trench does not reach rock at any point, but is sunk through mixed strata with beds of poor clay for a maximum depth of 41 feet below the ground level and 49 feet below top water level. Two 30-inch pipes, of which only one has been laid, pass from the reservoir through an outlet, shown at Figs. 22 and 23, Plate 5, and two similar pipes pass round the reservoir, in order that water may be drawn direct from the Llanforda Tunnel to the filter beds below.

*Filter Beds.*—From the Llanforda Tunnel outlet to the filter beds, the distance is about $\frac{3}{4}$ mile. The fall in this short length

*Fig. 24.*




is 112 feet, and part of the head is utilized to drive a three-cylinder Brotherhood engine at each filter bed, by means of which the sand washing cylinders are worked. The filter beds are of ordinary construction, except that in the arrangement of the under drains, special pains have been taken to secure uniform downward velocity. The section perpendicular to one of the main drains is shown at *Fig. 24*, on which it will be seen that 4-inch square tile drains are substituted for the usual coarse gravel. The walls and floors are of vitrified blue brickwork in

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Portland-cement mortar. There are two inlets to each reservoir, and each of these is provided with a disk-gauge, recording, in diagram form, the rate of supply to the filter beds at every instant. By these means, an exact knowledge of the duty of the filters under all the varying conditions of practical work is obtained.[1] From the filters the water passes to an uncovered clear water reservoir, having a capacity for the first instalment of 2,812,500 gallons. Here the rate of flow from the filters to Liverpool is recorded from instant to instant by a large disk-gauge.[1] This apparatus is exceedingly useful, as it enables one to see, at a glance, all changes that are made from time to time, in connection with the stop valves.

*Oswestry—Malpas Siphon.*—The length of this siphon is 17 miles 5 furlongs. The construction is generally similar to the former lengths, but the fall being increased to 6·87 feet per mile, the diameter of the pipes is reduced to 39 inches. The maximum head is 480 feet and occurs at the Wych Brook, where the water passes beneath the stream through steel tubes. On this length the Aqueduct passes, by cast-iron pipes in subways, under the Oswestry branch, and the Shrewsbury and Chester lines of the Great Western Railway. At Fig. 31, Plate 6, is shown an example of a railway crossing of this kind, but more exactly illustrating another case. At Hindford, the pipes were carried beneath the Shropshire Union Canal, in a bed of puddled clay.

*Malpas Balancing-Reservoir.*—The site of this reservoir being the top of a hill with approximately circular contours, lends itself to the construction of a single circular reservoir rather than a separate reservoir for each instalment of water. The space is adapted to the future construction of a reservoir to hold 6,000,000 gallons to 7,000,000 gallons; but as this was unnecessary in connection with the first instalment, a smaller circular reservoir to contain about 272,000 gallons was provided. This reservoir will serve as the valve well for the future main reservoir. It is constructed entirely of brickwork in Portland-cement mortar.

*Malpas—Cotebrook Siphon.*—This siphon passes, through subways, under the London and North Western Railway near Malpas and Beeston Castle respectively, and, in a puddled clay bed, beneath the Shropshire Union Canal near Beeston. The crossing near Malpas is illustrated at Fig. 31, Plate 6. The length of aqueduct

[1] These disk-gauges, or differentiating meters, are of the kind described by Mr. William Hope, Assoc. Inst. C.E., Minutes of Proceedings Inst. C.E., vol. cx. p. 260.

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is about 11 miles 5 furlongs; the fall is 4·6 feet per mile, and the pipes are 42 inches in diameter. The greatest head is about 308 feet.

*Cotebrook Balancing-Reservoir.*—Near Cotebrook the first of three intended balancing-reservoirs has been constructed. It is rectangular in section and contains 2,000,000 gallons at a depth of 15 feet.

*Cotebrook—Norton Siphon.*—The length of this siphon is 11 miles, the fall is 4·8 feet per mile, and the diameter 42 inches. The London and North Western Railway is crossed by a subway near Sutton Weaver station, in the same manner as in the former cases, and the water passes over the West Cheshire Railway near Delamere, through self-supporting wrought-iron tubes. The most important crossing on this siphon is that of the Weaver Navigation.

*Weaver Navigation Crossing.*—The waterway is about 100 feet wide and 15 feet deep. The work was carried out by laying the pipes below the bed of the Navigation, and without the construction of a tunnel, or the contraction of the waterway, or any interference with the traffic. The crossing is shown at Fig. 32, Plate 6, and consists essentially of three straight lengths of steel tubes, each 107 feet long, intended to pass the whole of the water of the three instalments, connected together laterally, temporarily closed at their ends, floated into position, and sunk into a trench previously dredged for the purpose to a depth of 23 feet below the water level. The land connections consist, as shown in the Figs., of cast-iron pipes tied together, where necessary, with links of wrought iron passing over hollow bosses cast on the pipes. At each embankment a coffer dam of timber sheet piling was driven and tied into the solid ground, at AA, Fig. 32, Plate 6, as shown on the left hand side of that Fig., in order to keep the embankments in position. The navigation was then dredged between the lines A and A, and a diver was sent down to straighten the bottom of the trench. When all was ready the triple tubes were floated into position and held at either end by cranes, while sufficient water was allowed to enter to give the tubes a very slight load in excess of their displacement. They were then permitted by the cranes to settle slowly down into their places, a single diver being able to guide them. The whole process of getting the tubes into position and sinking them occupied only fifteen minutes. At about 30 inches from each end of, and perpendicular to, the steel tubes, a rectangular cast-iron flange, C, 13 feet long and 6 feet deep, had been fitted for the purpose of making a joint with a second row of sheet piling, subsequently driven as shown

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at BB. The space between the sheetings was then filled in with clay. Doors left for the purpose at D in the piling A—opposite the end of the steel pipes—were then removed, and the cast-iron

*Fig. 27.*

NORTON WATER TOWER.

pipes were laid and connected. The tubes were then covered over with 18 inches of concrete.[1]

[1] This work was more fully described in the supplement to the *Engineer* 15 July, 1892, and in *Engineering*, 17 June, 1892.

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*Norton Water Tower.*—No site on the intended hydraulic gradient high enough for an ordinary reservoir could be obtained between the Cotebrook reservoir and the Prescot service reservoirs at the northern end of the aqueduct, a length of more than 20 miles. Norton Hill, about midway, was the most desirable position; but the intended hydraulic gradient passed over it at an altitude of 110 feet, and upon this hill the Norton Tower was therefore built. This tower, shown at Figs. 25 and 26, Plate 5, and in perspective at *Fig. 27*, is built of new red sandstone obtained in the neighbourhood of Norton and Runcorn. The tank is 80 feet in diameter and 31 feet deep at the centre. With the exception of the upper 10 feet 6 inches of its depth, it is constructed entirely of steel without support except at the circumference. The bottom of the tank is a basin of riveted steel plates, wholly in tension, depending from a steel rim in compression. The compression member is shown to an enlarged scale at Fig. 28, Plate 5. Upon the circular stone coping of the tower there is a cast-iron bed plate with a planed upper surface. Resting upon this bed plate, and supporting the compression member, is a ring of steel rollers, each 3 feet long and 6 inches in diameter, fished together at their ends. It will be seen from the Fig. that the rollers are 6 inches in diameter, but, being turned from steel bars 3 inches thick, they have a cheese-like section. Thus—the compression member being a ring capable of easy expansion and contraction circumferentially, and therefore radially, not only owing to changes of temperature but to changes of load—the rollers secure the masonry against all stresses, except those due to the vertical load and to wind pressure. It was, however, thought desirable, in view chiefly of the fact that the masonry work was new, to tie the bed plates together by winding plough-steel wire around them under a uniform strain, as in the case of the Vyrnwy Tower. The recess shown on the left hand side of the bed plate was thus filled and protected with asphalte. The ornamental cast-iron portion forming the upper 10 feet 6 inches of the tank is only connected with the steel portion through the medium of a comparatively thin expansion plate A, Figs. 25 and 28, Plate 5. This upper 10 feet 6 inches of the ornamental cast-iron portion rests upon another ring of castings, which form another ornamental member, but do not take the water pressure. These castings again rest upon the plinth of masonry shown at B. The space between this plinth and the compression member is accessible for examination through a door in the plinth. The standpipes from the three lines of main respectively, and that from the overflow, are passed through

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packing glands, shown at the bottom of the basin in Fig. 25, and on a larger scale at Fig. 29, Plate 5, and from these the basin requires no support. All parts of the tank are rendered accessible by a staircase resting upon and between the standpipes, as shown in Figs. 25 and 30. Immediately under the tank, a travelling gangway, shown on the same figures, is provided, which, by means of a winch, may be turned into any radius of the tower. In one position it provides access to the winding staircase, Figs. 25 and 30, and thus to the exterior of the tower above the water level. The tank contains, when full, about 650,000 gallons.[1]

The masonry of the tower is ashlar throughout, the principal stones ranging from 2 tons to 7 tons in weight.

The mortar is of Portland cement, and, in conformity with a practice always adopted by the Author, local materials are used so far as possible. Clean sand of the new red sandstone districts was therefore, subject to perfect bedding of the stones, permitted to be used, but great difficulty was at first experienced. Mortar so made is wanting in plasticity; and with every precaution, the stones, with beds sometimes of 20 square feet, could not, without excessive difficulty, be well and uniformly bedded. Crushed rock from clay-slate, as in the case of the Vyrnwy dam, or from igneous rocks or strong limestone, would have removed the difficulty; but a cheaper alternative was found in the retention of the natural sand of the district and the substitution — for the originally intended sand and Portland cement in the proportion of 2 to 1 —of 7 parts by volume of the sand of the district, 1 of poor lime, thoroughly slaked, and 4 of Portland cement. The working qualities of this mortar were excellent, and no further trouble occurred in bedding the stones perfectly. The mortar was used stiff, as in the case of the Vyrnwy dam, and was held in position by means of light laths on the stones already set. These laths were subsequently withdrawn, and the mortar joints were caulked with iron tools.

When a small proportion of lime is added to ordinary cement mortar, the hydrate of lime acts, while the mortar is plastic, as a

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[1] The Author desires to acknowledge that after designing and nearly completing the Norton Tower, he found that the principle of the basin in tension depending from a circular compression member, but differing from the Norton design in respect of the provision for expansion and contraction, had been employed in certain comparatively small water-towers in Germany. This principle of construction was theoretically investigated by Professor Intze, Zeitschrift des Vereines deutscher Ingenieure, 1886, vol. 30, p. 25. Tanks on the same principle, but of such size as not to require provision for expansion and contraction, were also constructed about 1875 by Messrs. Easton and Anderson.

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lubricator, and it fills the pores which the mechanically comminuted cement is incompetent to fill. It will probably never be reconverted into carbonate, and, as might be expected, the usual result is therefore a slight loss of tensile strength—amounting, in the case of the Norton Tower, to about 11 per cent.—but an increase of resistance to compression amounting, in the same case, to about 18 per cent. In the case of the Norton Tower the result justified the means, but equal plasticity and much greater strength can be attained with crushed rocksand in which the particles are properly proportioned.

The Norton Tower is a conspicuous object about a mile to the east of the London and North Western Railway between Crewe and Liverpool, three miles south of Runcorn. It may also be seen from a nearer point on the journey from Crewe to Warrington, four miles before reaching the latter place.

*Norton—Prescot Siphon.*—This length, of about 9¼ miles, as will be seen by reference to the plan, Fig. 1 and section, Fig. 2, Plate 4, crosses many railways and canals. The type of subway shown at Fig. 35, Plate 6, occurs under the Widnes branch of the Sheffield and Midland Joint Railway. Upon this siphon also occur the crossings under the Manchester Ship Canal, the River Mersey, the Bridgewater Canal, the Mersey and Irwell Canal (now abandoned), the Sankey Canal, as well as the Garston and Warrington branch, the St. Helen's branch, the Manchester branch and the Huyton and St. Helen's branch of the London and North Western Railway and the Sheffield and Midland and the Liverpool extension railways.

The cast-iron pipes of this siphon are 42 inches diameter, but under the Manchester Ship Canal and the Mersey, where steel pipes are used, the size is reduced to 36 inches and 32 inches respectively.

*Manchester Ship Canal Crossing.*—This work, Figs. 33 and 34, Plate 6, was carried out by cut and cover during the construction of the canal. It consists of a circular culvert of brickwork in cement, with terminal shafts 305 feet apart, and with provision for three lines of 36-inch steel pipes, Fig. 34, one of which is now in use. The culvert falls towards the Norton shaft, near the head of which there is a valve house containing a self-acting valve, and an engine house containing a hydraulic pumping engine, the motive power of which is the pressure of water in the main. The engine is started by a float in the sump below when the water reaches to a certain level, and ceases to work before the suction is uncovered. There is an automatic arrangement by which the pumps are primed with water before pumping begins. The

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expansion joint B at the top of the Mersey shaft is shown in detail at Fig. 36, Plate 6.

*Mersey Tunnel.*—In point of difficulty, this work proved to be the most important upon the whole aqueduct. It was the first tunnel ever constructed by means of a shield under a tidal or other river through entirely loose materials. The failure of the earlier attempts, the complete success finally attained, the causes of the change from failure to success, and the general features of the finished work have already been explained. They will therefore be merely summarized here.[1] The site was chosen as the best at which merely to lay the pipes in the muddy bed of the river, as has been quite successfully done elsewhere. A tunnel had not been contemplated, and for such a work the site was the worst possible. Parliamentary exigencies, however, forced a tunnel upon the Corporation, and there was no alternative but to accept the condition. The Author's specification recommended but did not enforce shield work; and he believes that the failure of the first contractors was due to the circumstance that they did not follow that recommendation. The second contractors did follow it, but the shield as at first used was too weak, and was otherwise not designed in the best manner. The damage to this shield did not occur, as has been suggested, by encountering cast-iron segments or other foreign materials belonging to the earlier attempt. At the end of forty-one months from the letting of the first contract, and at the end of twenty-one months from the letting of the second, only 239 feet out of the second contract tunnel had been driven. The changes he then made have already been described[2] by the Author, and four-and-a-half months after the recommencement of the work, the remaining three-quarters of the tunnel had been driven and lined with cast iron, through constantly varying, but always loose and water-bearing strata 51 feet below ordinary high-water mark. By a vote of the Corporation it had been decided to construct this tunnel of such size as to pass from Cheshire to Lancashire only two of the intended three instalments of water; and as the available head from Norton Tower to the Prescot service-reservoirs was sufficient to overcome increased friction, the diameter of the pipes was reduced both here and under the Ship Canal, from the normal 42 inches to 32 inches.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. pp. 100–104; Report of the British Association, 1892, p. 532; Transactions of the Liverpool Engineering Society, 1892–3, p. 49; and "Practical Tunnelling," by F. W. Simms, Crosby Lockwood & Co., London, 1896, p. 449.

[2] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 102.

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Two such pipes of riveted steel plates could be conveniently put together and repaired in a cast-iron tunnel 9 feet diameter within the flanges—involving an external diameter of 10 feet—and these sizes were therefore adopted. The steel plates of the pipes are $\frac{5}{8}$-inch thick, quite three times as great as is necessary to resist—with an abundant factor of safety—the static head of 363 feet; they are therefore unlikely to give trouble from leakage at the joints or otherwise, and, although with cast iron, a third line of pipes would have been out of the question, the Author would not hesitate to introduce a third line of such pipes as these. Except from condensation upon the iron, the tunnel is practically dry, but the same provisions for pumping are made as in the case of the Ship-Canal subway. Sections at and near the Cheshire shaft are shown at Fig. 37, Plate 6.

*Variation of Hydraulic Gradient.*—In designing aqueducts it has been usual to aim at the production of a uniform hydraulic gradient between the extremities of any siphon; but it is abundantly clear that uniformity of hydraulic gradient can only be justified by uniformity of cost. This principle has always been recognised in designing the relative dimensions and falls of aqueducts, consisting partly of tunnel or conduit not under pressure, and partly of siphon-pipes under pressure; and it was very early recognised by the late Mr. Thomas Hawksley in connection with the different parts of a conduit wholly under pressure. In long lines of pipes he did not hesitate to reduce valves of all kinds to one-third the waterway of the pipes upon which they were placed. In pipes of considerable length in relation to their diameters, the loss of head in a few valves having only one-third the area of the pipe is quite unimportant. Hence, both in the Rivington and Vyrnwy Aqueducts, the waterways of the stop-valves have been so reduced. A 40-inch or 50-inch stop-valve is very heavy and cumbrous, the difficulty of making it watertight is very great, it is difficult to open and close, still more difficult to prevent the momentum of the water from being suddenly arrested at the last instant of closing; it is moreover expensive, and is not required. In all parts of the Vyrnwy Aqueduct, the gradient has been permitted to change in such a manner, that from the inlet to the outlet of any siphon, the loss of head of each length bears a rational ratio to the cost of increased diameter; or in other words, given a loss between two points, the resistance to the flow of water at each intermediate point is reduced where it is cheapest to reduce it, and increased where —consistently with the sum of all the losses being equal to the total loss for which the siphon is designed—it is economical to increase



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it. Thus, for example, in all valves, and where the pipes pass under rivers or through tunnels in which exceptional economy results from reduction of size, the diameters are boldly reduced, and the lengths of simple shallow pipe-work are increased in diameter to the trifling extent necessary to gain the head required to balance the increased loss in other parts.

*Quality of Metals used in the Constructions.*—Except in connection with cast-iron pipes of large diameter, no exceptional difficulties arise in securing suitable metals for use in waterworks undertakings. The steel used in the Norton Tower, and in the various lengths of steel pipes, may be taken as typical of that used throughout the work. The compression member of Norton tank was required to have a minimum breaking strength of 32 tons and a maximum of 36 tons per square inch, with an elongation of at least 17 per cent. before fracture in a length of 8 inches. The ultimate resistance to shearing of the steel rivets was required to be 22 tons to 24 tons per square inch. Bessemer-steel bolts and nuts were required to bear a tensile stress of 30 tons per square inch. The milder steel for members, principally in tension, such as the basin of Norton tank and pipe work, was required to have a minimum breaking strength of 27 tons per square inch and a maximum of 31 tons per square inch, with an elongation of at least 25 per cent. before fracture in a length of 8 inches.

In connection with cast-iron pipes, however, considerable difficulties frequently arise. The metal of which a pipe is constructed may have abundant strength where subjected to compression or tension, but it may be greatly deficient in the qualities of toughness and elasticity which mild steel possesses in so high a degree.

In procuring from different parts of the country, under similar specifications and for similar purposes, large quantities of cast-iron pipes, the remarkable differences of their behaviour, notwithstanding the abundant sufficiency of their strength under tension and compression become evident. Pipes obtained from some parts of the country exhibit brittleness in an abnormal degree, and the difficulty is to place this tendency under proper control without unduly increasing the rejections of finished pipes. In the Vyrnwy work two transverse test bars were cast from the molten metal several times a day. In the ordinary course merely the ultimate transverse strength of such bars would be ascertained and the result might be delusive. It is almost impracticable to prepare a sufficient number of turned test-pieces from which to ascertain the elongation of the metal; the Author has, therefore, specified a

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minimum deflection of the transverse test-bars corresponding with the specified ultimate strength. This, for a bar 2 inches deep, 1 inch wide and 36 inches between the supports, was at first fixed at 0·28 inch on or before the application of the ultimate load of 28 cwts. It proved insufficient and has since been altered to 0·35 inch. In some places great difficulty is experienced in obtaining this result, although many of the best firms realise it in their ordinary practice.

The Paper is accompanied by thirty-seven drawings, from which Plates 4, 5 and 6, and the *Figs.* in the text have been prepared.



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## Discussion.

Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said the Authors were well known to the members of the Institution and required no introduction. The subjects of the Papers had also received the appreciation of engineers, and required no further commendation. All that remained for him under the circumstances was to ask the members, by passing a vote of thanks to the Authors, to show that the Papers were considered worthy of them and of the subject.

Mr. Deacon.

Mr. G. F. DEACON said, as he had spoken highly concerning certain results obtained from Portland-cement concrete, he wished to guard against the impression that he looked upon Portland-cement mortar or concrete as always necessary for such structures—structures in which the concrete was not necessarily subjected to running water, and in which it might stand one, or two, or more years before water-pressure was imposed upon it. The exigencies of such works were totally different from those of marine works. During the last two or three years he had undertaken a research on the subject of hydraulic limes. As a result of that research he particularly wished it to be understood that he should speak quite as favourably concerning hydraulic limes as concerning Portland cement if the occasion arose. His investigations had disclosed a fact that he had not been prepared for, viz., that both in tension and in compression hydraulic-lime mortar, made in the proportions of $3\frac{1}{2}$ to 1, might produce strengths equal to those of Portland-cement mortar made in the same proportions, resistances, in short, varying between 150 tons and 200 tons per square foot in compression, and between 200 lbs. and 300 lbs. per square inch in tension, with perfect water-tightness.

Mr. Mansergh.

Mr. MANSERGH, Vice-President, remarked that the elaborate descriptions and the beautiful illustrations would form very useful additions to the Proceedings of the Institution. The Papers were so good in themselves that there was little room for criticism; but on one point mentioned by Mr. Deacon he hoped to hear the views of many members who in the course of their practice had used concrete extensively. The methods adopted in the construction of the dams at Vyrnwy and at Thirlmere were essentially different. Mr. Hill had built many hundreds of thousands of yards of concrete in his time, and knew exactly what was done at Vyrnwy as well as at Thirlmere, and it was to be hoped that

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the members would hear what he had to say on that subject. Mr. Mansergh. Mr. Deacon had constructed the Vyrnwy wall in a manner in which a wall of that sort had never previously been constructed. It was made of heavy blocks of stone, set in very dry cement mortar, which had broken stone beaten into it, in the spaces between the blocks. The result claimed by Mr. Deacon was that the mass of the dam was exceedingly heavy and practically water-tight. Of course, the labour and the cost of constructing a wall in that way must be greater than if concrete were made in the ordinary way and large blocks simply inserted in it when in its wet condition, as was done at Thirlmere. Still, that cost ought to be incurred if the result justified the expenditure. Some years ago Mr. Mansergh had expressed in that room the opinion that it was quite hopeless to make water-tight concrete without plenty of water. He was then combating the common practice of putting in concrete intended to be water-tight exceedingly dry and without bringing it compactly together. He had previously seen one or two woeful examples of failure in which the materials were good; possibly there was too small a quantity of sand; but no attempt had been made to bring the material together by beating so as to make a solid mass of it; and in one place that he examined, the water passed in two minutes vertically through 6 feet of what was intended to be water-tight concrete, the water not being under pressure, but simply poured on the surface. Of course, that system was utterly wrong. It used to be the creed of many engineers and contractors that concrete ought not to be disturbed after it had been put in place. It was considered to be a sound principle that concrete should never be touched with a beater, or even with a shovel; and thirty years ago the practice was to tip concrete from a staging 6 feet, 8 feet or 10 feet high, the materials, of course, all separating, and producing no result whatever so far as soundness and water-tightness were concerned. The method of making concrete with plenty of water had been adopted by many engineers. In early days at Liverpool Mr. G. F. Lyster used to put in concrete dry, but he had ended by putting it in very wet. He had placed a photograph upon the wall of what might be considered the first masonry dam built for a waterworks reservoir (Abbeystead, near Lancaster) in England. Behind the structure shown on the photograph there was an old weir that had been constructed by Sir Robert Rawlinson about 1852. That was subsequently raised and thickened, and a puddle-wall was sandwiched between two rubble walls in 1864. In 1876 Mr. Mansergh had to raise the water-level about 15 feet, and he dared not build on the

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Mr. Mansergh. old structure. He therefore placed his wall in front of Sir Robert Rawlinson's original weir. It was 64 feet high and 40 feet above the apron. This wall was exceptionally thin, being only 7 feet 6 inches thick at the top and 24 feet at the bottom. If it were bearing the whole pressure of the water it would only have a factor of safety of 1·2. In addition to its being assisted behind by the old work, it ought to be stated that the wall was on a curve of 100 feet radius in plan. This wall was made of concrete in such a condition that, to use a Lancashire phrase, the men sank into it "shoe-top deep," and although thus light and thin, was perfectly sound and water-tight. He had placed on the table a cube of concrete made in exactly the same way, cut out of a mass about two months after it had been put in. It was 5 to 1 concrete made of sandstone, and came out of a tongue carrying a shoe for a puddle wall in the trench of a deep earthen bank. Under the byewash the tongue was carried up as a wall about 140 feet high and 6 feet thick. That, he believed, was absolutely tight; at all events, if not absolutely tight, it was an exceedingly slow filter. There was no perceptible leakage. The concrete was made of stone weighing only 145 lbs. to the cubic foot; the concrete weighing 133 lbs. That, he thought, was a very fair result. He fully agreed with all the precautions described by Mr. Deacon, especially with regard to having the materials used for concrete perfectly clean. Mr. Mansergh observed the same practice, and had always done so; and to that, he believed, was due the success of modern concrete in waterworks structures. He would ask what was the weight of the stone of which the Vyrnwy concrete was made. The weight of the concrete was given in the Paper as 156 lbs. to 158 lbs. Was the block of concrete weighed cut out of the solid wall, or made in the usual way—of broken stone, sand and cement? If it were cut out of the solid wall, of course it might be in great part a solid stone; an exact description of this concrete would be an assistance to the members in comparing the percentage of concrete to the stone of which it was made. The weight of the silurian rock used would, he supposed, be about 170 lbs. to a cubic foot. The finished dam had a specific gravity of 2·595—that was between 161 lbs. and 162 lbs. to a cubic foot—and that, of course, must be an exceedingly compact and sound structure. When he saw the dam in course of construction, he thought he had never seen a more magnificent piece of masonry in his life. In addition, he would like to know the actual cost per cubic yard of the dam.

It might be interesting to the meeting if a general comparison were made between the Thirlmere and the Vyrnwy undertakings

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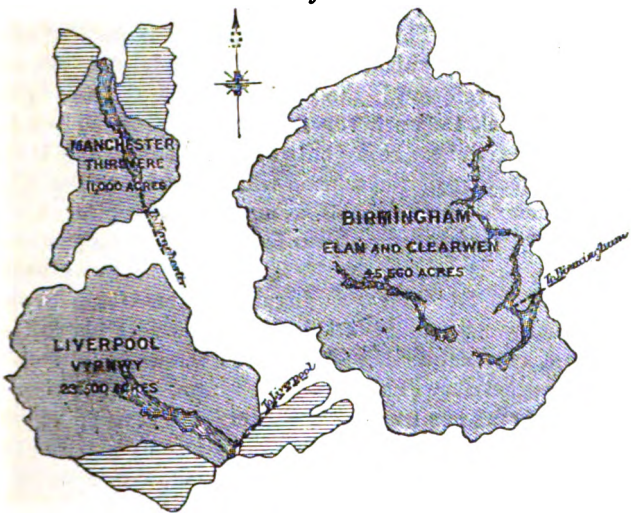
and the Birmingham gravitation scheme, which he was now carrying out. He had therefore placed upon the wall a cartoon, *Fig. 1*, which showed the relative drainage-areas of the three supplies. The Thirlmere area was about 11,000 acres, the Liverpool 23,500 acres, and the Birmingham 45,560 acres; so that practically Liverpool doubled Manchester, and Birmingham doubled Liverpool. The Thirlmere rainfall, according to eighteen years' gauging, was 85 inches, the rainfall in three consecutive dry years being 71 inches. The Vyrnwy rainfalls were not stated, but he hoped Mr. Deacon would furnish these data. On the Birmingham watershed—the Elan—the average rainfall was about 69 inches Mr. Mansergh.

*Fig. 1.*




MANCHESTER, LIVERPOOL AND BIRMINGHAM WATERWORKS—RELATIVE WATERSHEDS.

or 70 inches over a long term. Fortunately, a gauge had been kept at the foot of the watershed for twenty years, and this had been continued, and another put in, as the first was a little sheltered. Other gauges had also been erected at higher parts of the watershed, but these did not show that the mean fall of a long term would exceed 69 inches or 70 inches, the mean of three dry years being 55 inches or 56 inches. The Manchester works would ultimately supply 50 million gallons per day, and had to give 5½ million gallons in compensation. The Liverpool scheme was competent to supply 40 millions, the compensation being 13½ millions, and the Birmingham would yield about 75 millions for

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Mr. Mansergh. supply plus 27 millions for compensation, the latter merely for the purpose of securing the recreation of a few rod-fishers. Those who earned their living out of salmon-fishing by nets in the lower part of the Wye did not oppose the Bill, as they were certain that the prevention of floods, which would be effected to an enormous extent by the construction of the reservoirs, would be beneficial to them. The Corporation were asked in Parliament to give 40 million gallons in compensation, and at a cost of about £300,000, for the sake of a few men who went to throw a fly in the upper part of the river. The Thirlmere storage was 8,132 million gallons, the Vyrnwy about 12,000 million gallons, and Birmingham had on that watershed six reservoirs which held together 18,000 millions, the lowest of the series, the Caban Goch, holding just about as much as Thirlmere. The Thirlmere dam was about 50 feet above the river, and the Vyrnwy about 85 feet. The heights of the six dams to which he had referred in the Birmingham scheme were 122 feet, 128 feet, 120 feet, 101 feet, 109 feet, and 98 feet. They were all short dams, the highest being only 525 feet long at the top. There was another feature of the scheme which was he supposed unique. They commenced at the Frankley service-reservoir, 6 miles from the centre of Birmingham, at 600 feet above Ordnance datum, and had a rise in the aqueduct of 170 feet; so that they arrived at the River Elan 770 feet above Ordnance datum. The level of the river at the lowest dam on the shed was 700 feet above Ordnance datum, so that the aqueduct came up to the river 70 feet higher, and was carried forward through a tunnel to the narrow neck behind the great bend round the Foel. At that point what was called a submerged dam would be constructed, with its crest 780 feet above Ordnance datum. By that means the water would always be held up so as to charge the aqueduct. The top water of the Caban reservoir being 822 feet and the crest of the submerged dam 780 feet, there was a slice of water 42 feet thick, which would be first drawn upon to furnish both supply (first instalment 27 million gallons), through the aqueduct, and compensation, 27 millions, to the river at the main Caban dam. This slice would contain about 4,500 million gallons, and as the reservoir was drawn down it would (with the yield of the watershed) provide these 54 million gallons for about 100 days. When the water-level was lowered to 780 feet above datum, the 27 millions for supply must be drawn from the reservoirs higher up the valley, and the compensation water from the lower part of the Caban reservoir, which, as it contained 2,700 million gallons, would suffice for another 100 days if a drought should continue so long.

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Only the Pen-y-gareg and Craig-goch reservoirs on the Elan would need to be constructed, in addition to the Caban, to furnish the first instalment. The next work would be a tunnel from the Claerwen to Careg-ddu, laid at such a level as to drain the lowest reservoir on that river to above the submerged dam, so that the water of the Claerwen could be utilized before any reservoirs upon it were constructed. As the demand increased in the future, of course these reservoirs would have to be made. The aqueduct was nearly 74 miles long from the Elan to Frankley. About half of it would be constructed in tunnel and cut-and-cover on the hydraulic gradient line, of concrete and brickwork, and competent to discharge 75 million gallons a day, the fall being 1 in 4,000. The other half would consist ultimately of six lines of 42-inch iron or steel pipes in valley crossings, the first instalment requiring two of these, the fall being 1 in 1,760. The longest tunnels were 1¼ mile, 2½ miles and 4¼ miles in length. The longest siphon was 17 miles, and the greatest depth of the pipes below the hydraulic gradient line would be 550 feet, at the crossing of the River Severn near Bewdley. At that and other rivers, bridges would be built to carry the pipes. He would, in conclusion, direct attention to a model (exhibited) of the intended Elan and Claerwen reservoirs, the scale being 6 inches to 1 mile horizontally and 300 feet to 1 inch vertically. Mr. Mansergh.

Mr. A. W. Brightmore said, as he had been a resident engineer on some of the special works referred to by Mr. Deacon, he would make a few remarks on the Norton tank. When that tank was filled with water, the lowest point of the bottom deflected very nearly ⅜ inch; but when the tank was again emptied it resumed its former shape. When first filled, the tank was practically drop-tight. Afterwards, it was emptied again, and given a coating, on the inside, of cement mortar. The soluble part of the cement seemed to dissolve the rust in some of the joints, and caused some of them to leak slightly after the cementing was done; this was stopped by caulking. Rather a curious circumstance occurred after the charging of the main, when the water was being sent forward to Liverpool, and he happened to be on the top of the tank. The water in the tank beginning to rise without any apparent reason, he called to the walksman below to partly close the inlet-valve, as it seemed to be due probably to some of the sluice-drains, that had been previously opened, being shut down. But notwithstanding the gradual closing of the inlet-valve, the water continued to rise in the tank, till, all of a sudden, it presented the appearance of a huge boiling cauldron, waves being Mr. Brightmore.

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Mr. Brightmore. generated which caused the water to be thrown over the top of the tank. It appeared to be due to a large volume of air which had collected in the pipes coming forward, and rising up the hill on which the tower stood. Its volume naturally increased with the reducing pressure and pushed forward the water in front of it at a gradually-increasing rate, until the air itself, coming to the up-stand pipe of the tank, escaped and caused the ebullition referred to. If it had not happened that some one had been there to shut down the inlet-valve at the time, it was likely that the sudden release of so large a volume of air might have caused a concussion, owing to the water rushing into its place, and there might have been a burst, for which it would have been difficult to find a satisfactory explanation.

Mr. Hawksley. Mr. CHARLES HAWKSLEY said that his father, the late Mr. Thomas Hawksley, and Mr. Deacon had, as stated in the Paper, acted jointly in the passage of the Vyrnwy Bill through Parliament. That Bill received the Royal Assent in August, 1880, and in March of the following year the Corporation of Liverpool appointed Mr. Hawksley to "act as Engineer-in-Chief of the Corporation in carrying out of the works." In conformity with the terms of the agreement under which he was appointed, Mr. Hawksley designed the masonry dam of the Vyrnwy reservoir and much of the aqueduct for conveying the water from that reservoir to Liverpool. Mr. Charles Hawksley was not officially connected with the undertaking; but, owing to the circumstance that he was in partnership with his father, whilst the drawings prepared in accordance with his father's instructions—numbering over 400 principal drawings, and, including original sketches and duplicate copies, exceeding 3,000 altogether—were made in their office in Great George Street, Westminster, he naturally came to act as his father's assistant in connection with the Vyrnwy undertaking both in the office and, to some extent, in the engineering supervision of the work. He therefore, perhaps, might be allowed to say a few words on the subject of the second Paper.

When engaged in designing the Vyrnwy dam, Mr. Hawksley came to the conclusion that a work of that character and magnitude, the failure of which might involve great loss of life as well as destruction of property, ought to be made with a factor of safety of 2 or thereabouts. As mentioned in the Paper, Mr. Hawksley was much impressed with the possible effects of the up-lifting action of water which might find its way beneath the base of the dam. This element of calculation appeared seldom to have been taken into account previously, and the neglect of it was, in his

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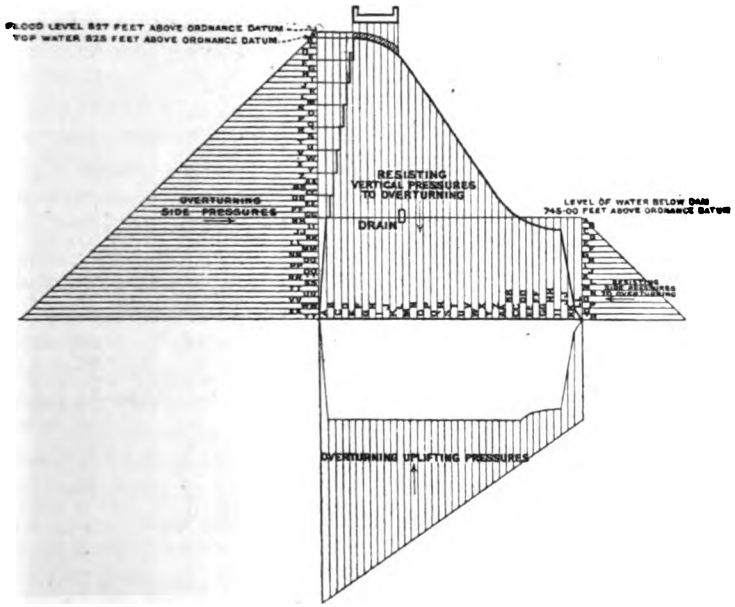
father's opinion, probably the cause of some of the failures that had unfortunately happened in the case of masonry dams. It might be of interest to the members to be enabled to follow the method of calculation adopted in determining the section of dam required to resist the overturning forces to which it would be subjected. He therefore exhibited an enlargement of one of the diagrams prepared in the course of the calculations, *Fig. 2.* In that diagram the horizontal lines on the water-side of the dam represented the over-turning forces of the water in the reservoir, whilst those on the opposite side of the dam indicated the re- Mr. Hawksley.

*Fig. 2.*


FLOOD LEVEL 827 FEET ABOVE ORDNANCE DATUM
TOP WATER 825 FEET ABOVE ORDNANCE DATUM
OVERTURNING SIDE PRESSURES
RESISTING VERTICAL PRESSURES TO OVERTURNING
DRAIN
LEVEL OF WATER BELOW DAM 745·00 FEET ABOVE ORDNANCE DATUM
OVERTURNING UPLIFTING PRESSURES

sistance exerted on the outer face of the lower portion of the dam by the water in the ground below the level of the stream. The vertical lines under the dam represented the up-lifting action of water which might accumulate beneath the base of the dam; and the vertical lines on the dam itself the resistance due to the weight of the masonry. The calculations were given in Tables I, II, III, and IV, the letters having reference to the horizontal strips and vertical strips respectively, the specific gravity of the water being taken as the unit. The calculated factor of safety was as nearly as possible 2. The section of the dam might strike

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Mr. Hawksley.

some persons as being heavy and strong when compared with the much lighter sections which had been built in some places, more especially in France. The failures which had, however, occurred, and notably one so recently as last year, should, in his opinion,

TABLE I.—RESISTING VERTICAL PRESSURES TO OVERTURNING.

| | Water. | Masonry above 745·00 not immersed in Water. | Masonry below 745·00 immersed in Water. | Leverage. | Moment. |
|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | Feet. | Feet. |
| *a* | 391·87 | .. | 140·6 | 113·38 | 60,371·4 |
| *b* | 231·00 | 40·00 | 225·0 | 110·00 | 54,560·0 |
| *c* | 171·00 | 200·00 | 225·0 | 107·00 | 63,772·0 |
| *d* | 111·00 | 360·00 | 225·0 | 104·00 | 72,384·0 |
| *e* | 89·00 | 552·00 | 225·0 | 101·00 | 82,416·0 |
| *f* | .. | 695·60 | 225·0 | 98·00 | 90,218·8 |
| *g* | .. | 681·60 | 225·0 | 95·00 | 86,127·0 |
| *h* | .. | 678·40 | 225·0 | 92·00 | 83,112·8 |
| *i* | .. | 673·60 | 225·0 | 89·00 | 79,975·4 |
| *j* | .. | 665·20 | 225·0 | 86·00 | 76,557·2 |
| *k* | .. | 656·00 | 225·0 | 83·00 | 73,123·0 |
| *l* | .. | 616·80 | 223·6 | 80·00 | 67,232·0 |
| *m* | .. | 540·50 | 224·4 | 77·00 | 58,897·3 |
| *n* | .. | 527·28 | 225·0 | 74·00 | 55,668·7 |
| *o* | .. | 491·28 | 225·0 | 71·00 | 50,855·9 |
| *p* | .. | 455·28 | 225·0 | 68·00 | 46,259·0 |
| *q* | .. | 419·28 | 225·0 | 65·00 | 41,878·2 |
| *r* | .. | 383·28 | 225·0 | 62·00 | 37,713·4 |
| *s* | .. | 347·28 | 225·0 | 59·00 | 33,764·5 |
| *t* | .. | 311·28 | 225·0 | 56·00 | 30,031·7 |
| *u* | .. | 275·28 | 225·0 | 53·00 | 26,514·8 |
| *v* | .. | 239·28 | 225·0 | 50·00 | 23,214·0 |
| *w* | .. | 203·28 | 225·0 | 47·00 | 20,129·2 |
| *x* | .. | 167·28 | 225·0 | 44·00 | 17,260·3 |
| *y* | .. | 131·28 | 225·0 | 41·00 | 14,607·5 |
| *z* | .. | 95·28 | 225·0 | 38·00 | 12,170·6 |
| *aa* | .. | 61·60 | 225·0 | 35·00 | 10,031·0 |
| *bb* | .. | 32·00 | 225·0 | 32·00 | 8,224·0 |
| *cc* | .. | 10·40 | 225·0 | 29·00 | 6,826·6 |
| *dd* | 1·87 | .. | 220·5 | 26·00 | 5,781·6 |
| *ee* | 6·60 | .. | 213·2 | 23·00 | 5,055·4 |
| *ff* | 10·90 | .. | 206·5 | 20·00 | 4,348·0 |
| *gg* | 12·60 | .. | 202·5 | 17·00 | 3,656·7 |
| *hh* | 14·10 | .. | 200·0 | 14·00 | 2,997·4 |
| *ii* | 15·00 | .. | 199·0 | 11·00 | 2,354·0 |
| *jj* | 41·00 | .. | 162·0 | 8·00 | 1,624·0 |
| *kk* | 93·00 | .. | 73·7 | 5·00 | 833·5 |
| *ll* | 148·70 | .. | 14·6 | 1·87 | 305·4 |
| | | | | Total | 1,410,852·3 |

act as a warning to engineers to provide an ample margin of safety. During the present year there were rumours that another dam, of somewhat similar section to that shown in a diagram, which gave way last year, had been in danger. Its failure was

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apprehended, but as all mention of it in the newspapers had ceased, it was to be hoped the dam had withstood the pressure to

Mr. Hawksley.

TABLE II.—RESISTING SIDE PRESSURES TO OVERTURNING.

| | Water. | Leverage. | Moment. | | Water. | Leverage. | Moment. |
|---|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | | Feet. | Feet. | Feet. |
| *a* | 3·1 | 43·75 | 135·6 | | Brought forward | | 8,866·7 |
| *b* | 9·4 | 41·25 | 387·7 | | | | |
| *c* | 15·6 | 38·75 | 604·5 | *k* | 65·6 | 18·75 | 1,230·0 |
| *d* | 21·9 | 36·25 | 793·9 | *l* | 71·9 | 16·25 | 1,168·3 |
| *e* | 28·1 | 33·75 | 948·4 | *m* | 78·1 | 13·75 | 1,073·8 |
| *f* | 34·4 | 31·25 | 1,075·0 | *n* | 84·4 | 11·25 | 949·5 |
| *g* | 40·6 | 28·75 | 1,167·2 | *o* | 90·6 | 8·75 | 792·7 |
| *h* | 46·9 | 26·25 | 1,231·1 | *p* | 96·9 | 6·25 | 605·5 |
| *i* | 53·1 | 23·75 | 1,261·1 | *q* | 103·1 | 3·75 | 386·7 |
| *j* | 59·4 | 21·25 | 1,262·2 | *r* | 109·4 | 1·25 | 136·7 |
| | Carried forward | | 8,866·7 | | | Total | 15,209·9 |

TABLE III.—OVERTURNING SIDE PRESSURES.

| | Water. | Leverage. | Moment. | | Water. | Leverage. | Moment. |
|---|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | | Feet. | Feet. | Feet. |
| *a* | 2·0 | 126·00 | 252·0 | | Brought forward | | 174,672·8 |
| *b* | 8·1 | 123·75 | 1,002·3 | *aa* | 164·3 | 61·25 | 10,063·3 |
| *c* | 14·4 | 121·25 | 1,746·0 | *bb* | 170·6 | 58·75 | 10,022·7 |
| *d* | 20·6 | 118·75 | 2,446·2 | *cc* | 176·8 | 56·25 | 9,945·0 |
| *e* | 26·8 | 116·25 | 3,115·5 | *dd* | 183·1 | 53·75 | 9,841·6 |
| *f* | 33·1 | 113·75 | 3,765·1 | *ee* | 189·3 | 51·25 | 9,701·6 |
| *g* | 39·4 | 111·25 | 4,383·2 | *ff* | 195·6 | 48·75 | 9,535·5 |
| *h* | 45·6 | 108·75 | 4,959·0 | *gg* | 201·8 | 46·25 | 9,333·2 |
| *i* | 51·9 | 106·25 | 5,514·3 | *hh* | 208·1 | 43·75 | 9,104·3 |
| *j* | 58·1 | 103·75 | 6,027·8 | *ii* | 214·4 | 41·25 | 8,844·0 |
| *k* | 64·4 | 101·25 | 6,520·5 | *jj* | 220·6 | 38·75 | 8,548·2 |
| *l* | 70·6 | 98·75 | 6,971·7 | *kk* | 226·9 | 36·25 | 8,225·2 |
| *m* | 76·8 | 96·25 | 7,392·0 | *ll* | 233·1 | 33·75 | 7,867·1 |
| *n* | 83·0 | 93·75 | 7,781·2 | *mm* | 239·4 | 31·25 | 7,481·2 |
| *o* | 89·2 | 91·25 | 8,139·5 | *nn* | 245·6 | 28·75 | 7,061·0 |
| *p* | 95·5 | 88·75 | 8,475·6 | *oo* | 251·9 | 26·25 | 6,612·4 |
| *q* | 101·8 | 86·25 | 8,780·2 | *pp* | 258·1 | 23·75 | 6,129·8 |
| *r* | 108·1 | 83·75 | 9,053·3 | *qq* | 264·4 | 21·25 | 5,618·5 |
| *s* | 114·4 | 81·25 | 9,295·0 | *rr* | 270·6 | 18·75 | 5,073·7 |
| *t* | 120·6 | 78·75 | 9,497·2 | *ss* | 276·9 | 16·25 | 4,499·6 |
| *u* | 126·8 | 76·25 | 9,668·5 | *tt* | 283·1 | 13·75 | 3,892·6 |
| *v* | 133·1 | 73·75 | 9,816·1 | *uu* | 289·4 | 11·25 | 3,255·7 |
| *w* | 139·3 | 71·25 | 9,925·1 | *vv* | 295·6 | 8·75 | 2,586·5 |
| *x* | 145·6 | 68·75 | 10,010·0 | *ww* | 301·9 | 6·25 | 1,886·9 |
| *y* | 151·8 | 66·25 | 10,056·7 | *xx* | 308·1 | 3·75 | 1,155·3 |
| *z* | 158·1 | 63·75 | 10,078·8 | *yy* | 314·4 | 1·25 | 393·0 |
| | Carried forward | | 174,672·8 | | | Total | 341,350·7 |

which it had been subjected, and if needed some means had been taken for strengthening it.

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Mr. Hawksley. The Corporation of Liverpool having prudently determined to construct the Vyrnwy dam without the intervention of a contractor, it became needful to devise the mode in which the building operations were to be carried out—a matter of considerable importance in view of the necessity for avoiding disturbance of recently executed masonry by working or travelling upon it before the cement mortar had become quite set and so hardened as not to be prejudicially affected by the consequent vibration. After much

TABLE IV.—OVERTURNING UPLIFTING PRESSURES.

| | Water. | Leverage. | Moment. | | Water. | Leverage. | Moment. |
|---|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | | Feet. | Feet. | Feet. |
| *a* | 386·72 | 113·4 | 43,854·0 | | Brought forward | | 334,172·6 |
| *b* | 234·70 | 110·0 | 25,817·0 | | | | |
| *c* | 228·40 | 107·0 | 24,438·8 | *u* | 113·30 | 53·0 | 6,004·9 |
| *d* | 222·00 | 104·0 | 23,088·0 | *v* | 106·90 | 50·0 | 5,345·0 |
| *e* | 215·60 | 101·0 | 21,775·6 | *w* | 100·70 | 47·0 | 4,732·9 |
| *f* | 209·20 | 98·0 | 20,501·6 | *x* | 94·10 | 44·0 | 4,140·4 |
| *g* | 202·80 | 95·0 | 19,266·0 | *y* | 87·80 | 41·0 | 3,599·8 |
| *h* | 196·40 | 92·0 | 18,068·8 | *z* | 81·40 | 38·0 | 3,093·2 |
| *i* | 190·00 | 89·0 | 16,910·0 | *aa* | 75·00 | 35·0 | 2,625·0 |
| *j* | 183·60 | 86·0 | 15,789·6 | *bb* | 68·60 | 32·0 | 2,195·2 |
| *k* | 177·20 | 83·0 | 14,707·6 | *cc* | 62·20 | 29·0 | 1,803·8 |
| *l* | 170·80 | 80·0 | 13,664·0 | *dd* | 57·70 | 26·0 | 1,500·2 |
| *m* | 164·50 | 77·0 | 12,666·5 | *ee* | 56·10 | 23·0 | 1,290·3 |
| *n* | 158·10 | 74·0 | 11,699·4 | *ff* | 53·40 | 20·0 | 1,068·0 |
| *o* | 151·70 | 71·0 | 10,770·7 | *gg* | 49·20 | 17·0 | 836·4 |
| *p* | 145·30 | 68·0 | 9,880·4 | *hh* | 44·40 | 14·0 | 621·6 |
| *q* | 138·90 | 65·0 | 9,028·5 | *ii* | 39·00 | 11·0 | 429·0 |
| *r* | 132·50 | 62·0 | 8,215·0 | *jj* | 68·00 | 8·0 | 544·0 |
| *s* | 126·10 | 59·0 | 7,439·9 | *kk* | 102·60 | 5·0 | 513·0 |
| *t* | 117·70 | 56·0 | 6,591·2 | *ll* | 147·00 | 1·87 | 274·9 |
| | Carried forward | | 334,172·6 | | | Total | 374,790·2 |

$\frac{1,426,062 \cdot 2}{716,140 \cdot 9} = 1 \cdot 9913$ factor of safety (excluding wind pressure).

$\frac{1,426,062}{716,834 \cdot 9} = 1 \cdot 989$ factor of safety (including wind pressure).

consideration, it was determined to carry the cranes on a timber scaffolding, on which should also travel the wagons for conveying the stones to the cranes and the light locomotives intended to be employed in hauling them. The difficulty was to carry such a scaffolding without causing vibration to the freshly-built masonry over which the scaffolding had to advance. That difficulty it was proposed to overcome by leaving small wells in the masonry, at intervals of about 18 feet, into which were to be inserted timber masts to carry the platform of the scaffolding, the masts being

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kept free from contact with the masonry except at the foot, where they would rest on masonry, which had been executed for a sufficient length of time to enable the mortar to become thoroughly hardened. It was intended to lift this scaffolding from time to time as the masonry rose in height by means of the steam cranes at work upon it, the small wells being filled in with masonry at each change in position of the masts. The details of this system of scaffolding had been completely worked out, and the drawings for its construction prepared; when Mr. R. C. Rapier, M. Inst. C.E., suggested that if the cranes were made with jibs having a radius of sufficient length to extend beyond the side of the wall, the whole of the materials might be hoisted from wagons travelling on the surface of the ground at the foot of the wall. Further, that the cranes might be made to travel up inclines on the wall itself, at a distance from one another sufficient to enable the cement mortar employed in the masonry already deposited by one crane to become hardened, before the next following crane travelled over the work which had been built with the assistance of its predecessor. This suggestion was, after careful deliberation, adopted in preference to the scaffolding previously referred to, and it was by this method that the wall was for the most part constructed. Eight cranes were employed, following one another at intervals. When the cranes (each of which weighed about 38 tons) successively reached the end of the wall, they were lifted by a hydraulic ram, and turned so that they passed across the width of the wall and travelled back across the side of the wall opposite to that which they had previously traversed, being again employed in building as they progressed. Mr. Hawksley.

For reasons which need not here be entered into, Mr. Hawksley retired from the undertaking in September, 1885. The masonry of the dam had then been carried up to about the height of the top of the outlet-tunnels, rather more than half the entire cubic contents of the wall having been executed. The dam was subsequently completed in accordance with Mr. Hawksley's design, with the exception of the arches carrying the roadway, which were made of elliptical shape instead of segmental as originally intended, a variation being also made in the design of the parapets. At the time of Mr. Hawksley's retirement, nearly the whole of the aqueduct from the Vyrnwy reservoir to Liverpool had been finished, but there remained to be carried out the following principal works:—The Oswestry reservoir and filter-beds, three balancing-tanks, the Norton water-tower, the railway-crossings, the crossings of the Weaver Navigation and the River Mersey, as

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Mr. Hawksley. well as the outlet and gauging arrangements at the Vyrnwy dam. To the foregoing must be added the Vyrnwy water-tower and the conduit connecting it with the outlet tunnel, which were devised by Mr. Deacon for the purpose explained in the Paper. The whole of these works were subsequently carried out by Mr. Deacon, who on the retirement of Mr. Hawksley became the Engineer-in-Chief of the undertaking. Mr. Charles Hawksley's association with the Vyrnwy works naturally came to an end on the retirement of his father, so that he would not further remark upon them, except to say that it was his father's intention to have carried the aqueduct under the River Mersey by means of a tunnel of sufficient diameter to receive three lines of 42-inch pipes. This tunnel was to have been driven in the hard sandstone rock at a depth of about 120 feet below the bed of the river, thus avoiding the loose materials beneath the river which had been alluded to in the Paper as having caused much difficulty in the execution of the work. With regard to the observation that structures like the Vyrnwy dam had seldom been sufficiently water-tight to satisfy the legitimate aspirations of engineers, he might remark that if the leakage from the Vyrnwy dam was less than that from the dams of Gileppe and Furens, it was gratifying evidence of the solidity and water-tightness of the structure.

Mr. Symons. Mr. G. J. SYMONS had but little to say, except that the three works mentioned, including Birmingham, fully justified the ambitious phrase descriptive of the object of the Institution, viz., "the art of directing the Great Sources of Power in Nature for the use and convenience of man." He ventured to think these three works might well be taken as typical of the highest class of engineering. It was a pleasure to him to have been associated in however small a way with such successful works. He was more especially concerned in relation to the available quantity of water on the three grounds. The Birmingham scheme was not then before the Institution in any detail, and a discussion on the quantities on that ground would be better postponed until the time when Mr. Mansergh should bring forward a Paper analogous to the others, giving the details of the execution of that undertaking. With regard to the Thirlmere works, Mr. Hill had pointed out that when they were commenced very little was known as to what the rainfall was in that district. That was true, although of course observations in the vicinity, but not on the gathering ground, had been made for a number of years. In referring to the evidence he gave in 1878, he hoped no one would fancy that he was conceited —as his only object was to show how closely it was often possible

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to arrive at the rainfall, even in the absence of actual observations on the ground. Part of the observations had been made in connection with an earlier scheme, which he confessed he was almost sorry had not been carried out as a great national work—that of Messrs. Hemans and Hassard for the utilization of the three great English lakes. Ullswater was the lowest of the three Cumberland lakes, and the scheme was that Thirlmere and Haweswater should each be raised and utilized by diversion into Ullswater, which was to become the great storage reservoir from which an aqueduct was to conduct the water south to London. In connection with that, somewhere about 1866, he was asked to set up a certain number of gauges over the district. The district was so large that, being limited to about a dozen gauges, they were necessarily at considerable intervals, including only two on Thirlmere, one at the parsonage at Wythburn and another on Helvellyn. They had been established for some years, and formed practically the chief data for his estimate of what the fall would be. The evidence he had given was that the mean yearly fall would be "nearly 90 inches." They now had from Mr. Hill a mean of 85·02. That was not a bad estimate, but the other parts were better. For water-supply purposes, the mean of three consecutive dry years was wanted. He had said that it would probably be "72 inches": the figure now given was 70·8 or 1·2 minus. In the driest year, he had said that the fall would be "60 inches," but it turned out to be 61·6, or 1·6 in excess. The result, he thought, showed that even without actual observations the estimates of rainfall were not altogether so irregular and unreliable as some persons imagined. He agreed in regretting the absence of any figures except the vague statement that the rainfall "exceeded 70 inches" at Vyrnwy. Gauges were kept there, and he hoped some day the records would be given to the public, as he could not see what was the use of keeping them back. He certainly admired the Norton Tower, but he did not understand why all the inscriptions should be in Latin. He was a great admirer of Latin, and if there was to be one uniform language no doubt it would be the best; but as it was not a language of any living nation, he thought that English inscriptions would have been better. When the Thirlmere scheme was being advocated, there was a strong local opposition that the beauty of the country was going to be ruined. His impression was that engineers as a rule improved a place rather than spoilt it. Only recently, when in the Lake district, he drove round the road on the west side of the lake, and a more charming drive he did not think existed in the district.

Mr. Symons.



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Mr. Vernon-Harcourt.

Mr. L. F. VERNON-HARCOURT said he had an opportunity on one occasion, by the kindness of Mr. Deacon, of seeing the Vyrnwy works, and he thought everyone must agree in the view that in such reservoir works, engineers had really improved upon nature by providing a beautiful sheet of water which would look perfectly natural, except that when he saw it there were roads and hedges going down into the water, which no doubt had since disappeared. With regard to the water-tightness of dams, he quite agreed that some dams abroad were not water-tight, and that it was important that large masonry dams should not be subject to percolation. For example, the Gileppe dam in Belgium let a large amount of water through it, though it was an exceptionally thick dam. He might have been unfortunate on the occasion on which he saw the Furens dam in 1892, which was about 175 feet in height from the foundations to the highest water-level. When he was there, it was possible the reservoir was not full, but it was not very far from full, and he certainly did not notice any leakage. It was a beautiful work amongst very picturesque surroundings; and while not having the length of the Vyrnwy dam, it had a greater height, and it seemed to him to be a perfect dam. With regard to the Bouzey reservoir dam that failed last year in France, he thought the failure might be attributed, by anyone who had seen the section, to faults in the design. Moreover, it rested upon fissured sandstone rock, and he therefore did not think it was surprising it should have failed. It was a very long dam, and it retained a large quantity of water; but it certainly was defective in design, and very unlike the dam at Furens, which showed that French engineers could design dams that would retain a great head of water satisfactorily. He had not had an opportunity of seeing the Thirlmere works, but he should like to ask whether any damage had resulted to the lands bordering the lake, on account of the lowering of the raised water-level by the drawing off of the supply. It was well known that when water was sometimes on land and sometimes off, the portion between the greatest height and the lowest point was liable to be to a certain extent disfigured. He should be glad to know whether this anticipation had been realised, or whether there was no more in it than in some other anticipations that had been entertained. The two Papers under discussion, and the reference to the works in course of construction for supplying Birmingham, could not fail to arouse attention to the fact that, with the exception of the metropolis, the largest cities of the kingdom, including Glasgow, which was

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supplied from Loch Katrine, had been provided, in an abundant measure, with the purest form of water-supply. This consideration led naturally to a regret that London, owing to its remoteness from uninhabited mountainous districts, did not possess an equally perfect supply. Schemes had, indeed, been brought forward, some thirty years ago, for bringing a supply of water to London from Wales or from the Cumberland lakes; but the great cost of bringing water from such a distance, and the large vested interests in the existing sources of supply, had hitherto precluded London from being placed on a level in this respect with Manchester, Liverpool, Birmingham and Glasgow. Mr. Vernon-Harcourt.

Mr. A. R. Binnie found it difficult to criticise the Papers. He did not know whether to admire more the perspicuity, accuracy and condensation of Mr. Hill's description of his large works, or the wealth of detail and the many ingenious contrivances that Mr. Deacon had displayed. Of one thing he was perfectly sure—that the Institution would long be indebted to the Authors for two of the ablest Papers that had ever been written on that particular branch of engineering practice. Not only were the Papers valuable in themselves, but they had been the means of eliciting from Mr. Mansergh remarks on another large work, that for the supply of Birmingham, and from Mr. Hawksley what might be regarded as a bequest from his father, showing the mode in which his calculations of the stability of a large dam had been made. Anyone who had had the privilege of knowing the late Mr. Hawksley would value it as a very important contribution to the Proceedings. After saying this it would appear almost ungrateful to attempt to adopt anything like the language of criticism; but he could not altogether agree with Mr. Deacon in some of his remarks as to the construction of concrete. He admitted that that concrete was perhaps about the best, if not absolutely the best, he had ever seen; but he did not attribute the excellence of that concrete altogether to its excessive dryness. There were on the table specimens of the concrete made by Mr. Deacon's method, and Mr. Mansergh exhibited a cube of concrete made in a very different manner. Anyone inspecting those two specimens would, he thought, have some difficulty in deciding which was the better and the more solid. As Mr. Deacon had described it, the concrete which he made had been the result of much ramming, the concrete containing a very small amount of water. The concrete of which Mr. Mansergh had exhibited a specimen was made with rather a larger amount of water than was generally used in concrete work. In his own mind he always divided concrete into two Mr. Binnie.



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Mr. Binnie. kinds. One was concrete necessary for supporting a weight in foundations where water-tightness was not an absolute necessity, and which under those circumstances might be made with considerable ease, without adopting those other precautions which were necessary when water-tight work had to be secured. When water-tightness was a necessity, he had found there were two points to be observed:—First, that, amalgamated with the stone, there should be an excess of sand greater than the absolute vacuities existing among the stones. That he held to be the first and essential requirement of water-tight concrete. The next was that the concrete should be well worked—not necessarily rammed, but worked with shovels—and so rendered with regard to moisture, that there could be no doubt that the finer particles of the sand and the smaller particles of the stone would settle down by their own weight among the larger portions of the broken stone which formed the bulk of the concrete. It was acting on those principles that the block exhibited by Mr. Mansergh was made. Another point upon which he might remark incidentally, was the possible economy that might be effected in long lines of pipe by the contraction of the area at certain points of the work, such as valves, at critical points of bridges, and other places where economy of construction was of paramount importance. In those cases it became a matter of judgment for the engineer to determine how much head could be sacrificed in overcoming the resistance due to passing through a smaller orifice than the full sectional area, without unduly weighting the work with a loss of head incommensurate with the object ultimately in view.

With the account of these three great works which were more or less fully displayed before him, he could not refrain from drawing one conclusion, viz., that they were avowedly designed and constructed for the purpose of giving large communities the best possible supply of water. To obtain that purity of supply which had been considered necessary in the past, it had been decided to go to distances between 80 miles and 100 miles to provide a proper supply for a population of 500,000. It was a grave question, reading the literature of the day and observing the official declarations, as to whether the members were not contemplating that evening a gigantic waste of money. They had recently been told, on high official authority, that, when supplying a few millions of people with water, it was immaterial whether in the water-supply there was mixed up the excreta of another million of people. That had been placed before them as an important official determination. It had been said that it could be done with perfect safety to those

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who drank the water. If that was the case—and it became a serious consideration for members of the profession who were largely responsible for the sanitation of many millions of people—it must be acknowledged that to a large extent the works which they were contemplating were rapidly becoming matters of the past; for if with impunity a large population could be supplied with water containing the excreta of another million people, clarified as best could be done, the question arose whether they might not be forced in time to apply that rule with rigid accuracy. He would leave them to draw the logical conclusion from the premises that had been laid down. He felt certain that whatever might be said with regard to the future, a debt of gratitude had been incurred to those who in the past had raised the sanitation of the country to the position which it now occupied. To Mr. Thomas Hawksley, to Mr. Bateman (who was connected with the Manchester works for so many years), and to many others, a great debt of gratitude was due for the high sanitary condition of the United Kingdom at the present time; and it behoved engineers to see that the principles which had been productive of so much good were not in the future violated. Mr. Binnie.

Mr. W. B. Lewis wished to emphasise a remark that had fallen from Mr. Symons, and was confirmed by Mr. Vernon-Harcourt. When the Vyrnwy scheme was before Parliament, he had to go down on behalf of the Severn cities to the site, and a more dreary spot he scarcely ever visited. It was a remarkable valley, surrounded by low-crowned mountains or hills, and with a very flat bottom. Some two years ago he saw the completed reservoir, and it would be impossible to overrate the increased beauty of the place. It was one of the prettiest spots one could visit, and not only was the lake very beautiful, but the water-tower was an object that harmonised with the scenery; the whole was a matter as to which even if laid out merely for æsthetic effect the designer might be proud. Mr. Lewis.

Mr. J. Wolfe Barry, C.B., Vice-President, asked the Authors whether they could add to the value of their communications by giving some approximate indication of the price of concrete and masonry in those large dams. The information would be useful as a guide to members who had to deal with similar large structures in the future; and it would also be interesting to compare the cost of the different kinds of manipulation employed in the two works. He would also inquire why Mr. Deacon did not adopt the plan of passing the aqueduct under the Mersey in the solid rock in preference to taking it through the alluvial deposit. No Mr. Wolfe Barry.

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Mr Wolfe Barry. doubt there was some good reason for that choice, but it would at first sight appear that the original idea of making use of the solid bed of rock would have been more economical, and he should think it would not have affected the hydraulic gradient in any material manner.

Mr. Wells. Mr. LIONEL B. WELLS said when the Liverpool Water Bill was before Parliament, a question was raised as to whether the River Weaver Navigation should be crossed by means of a tunnel or by pipes laid in the bed of the river. He had reported to the Weaver Trustees, that either method might be carried out satisfactorily. The Trustees were anxious to have a tunnel, so that the navigation would be left uninterrupted, and that the pipes might be repaired at all times. Seeing that this course was adopted under a very much larger navigation close by, the Manchester Ship Canal, it appeared as if the Liverpool authorities preferred a tunnel, and recognised the facilities secured by this method. Parliament left the question to be decided by the Board of Trade, who allowed the pipes to be laid in a trench dredged in the bed of the river, as Mr. Deacon had proposed, and so far it had answered perfectly. It appeared, therefore, that in future navigable rivers might be crossed in the manner adopted successfully at the Weaver, with the sanction of the Board of Trade; and therefore it was a matter of some importance to know what was likely to be the cost of carrying out works in that manner.

Mr. Beloe. Mr. C. H. BELOE, having had something to do with the management of the Vyrnwy works in his capacity as a member of the Corporation of Liverpool, would say a few words on the practical result of those works since they passed out of Mr. Deacon's control. One point of similarity between the designs described in the two Papers was very striking, viz., the use of straining-towers both at Vyrnwy and at Thirlmere; and he would be glad to know the result of the working of the Thirlmere straining-tower. Reference had been made to the picturesque effect of the straining-tower at Vyrnwy. He was free to admit that it had a most picturesque effect, and was a remarkable example of Mr. Deacon's well-known ingenuity in contriving mechanical appliances to effect whatever was desired automatically. The tower as designed was intended practically to take care of itself. Whenever one of the gauze cylinders became so clogged as to be unable to pass the requisite quantity of water, it was supposed automatically to ring a bell to signify that it required assistance. Unfortunately that bell was not in use, but the beauty of the machinery, the manner in which the cylinders were raised, and the appliances for washing them, excited the

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admiration of everyone who witnessed the operations. He must say he thought the money spent on that straining-tower might have been spent in other ways to better advantage. The gauze on the cylinders was a continual source of annoyance; it was constantly failing through perforation, and the result of the straining was not satisfactory. Another point open to criticism in the design of the Vyrnwy works was the construction of the filter-beds at Oswestry. The filter-beds were formed in a very different manner from those designed by the late Mr. Hawksley for the Rivington works, which had been at work a considerable period, and continued to give the greatest satisfaction. There was no preliminary straining at Rivington through gauze cylinders; but at Vyrnwy, in spite of such straining, the filtration effected by the Oswestry filters was not at all satisfactory. In consequence, large additional filter-beds were in course of construction to enable the Corporation to filter the water conveyed by the first line of pipes to the Oswestry filter-beds. It was interesting to notice that in both the works under discussion this copper-wire gauze straining had been adopted. He was acquainted with the result of the process at the Vyrnwy, but not at Thirlmere. A statement of the experience gained in that case would be valuable, and also the nature of the filtration which the Thirlmere water received after it was delivered at Manchester—presuming that it received some filtration over and above that effected by the gauze strainers. The question of filtration of the Vyrnwy water had received much attention from the present waterworks engineer to the Liverpool Corporation, Mr. Joseph Parry; but so far as he could see, nothing had yet been devised to induce him to depart from sand filtration, and from the design of the filter-beds as constructed at Rivington. Mr. Parry had conducted most elaborate experiments with the aid of the "tintometer"—an instrument that showed the percentage of decolorization effected by different modes of filtration; and it would be to the advantage of the Institution if Mr. Parry could be induced to give the benefit of those experiments on both the Rivington and the Vyrnwy water, and the result of filtration by the two filter-beds referred to. The question of filtration was of course always important in dealing with water derived from peaty valleys like the Vyrnwy, and from the moorlands at Rivington. The result was practically established, that the older the filter-bed, and the less it was disturbed, the better it effected the decolorization of peaty water. Mr. Beloe.

Mr. JAMES WATSON was at present engaged in the construction of a masonry dam of considerable dimensions for impounding Mr. Watson.

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Mr. Watson. compensation water for Bradford. The two Papers opened up the great question of the administration of public works, whether they should be executed through a contractor or by a corporation or company. That, of course, in itself, involved many considerations. The Papers being in juxtaposition, it would be interesting to know something as to cost. Mr. Deacon had enjoyed all the advantages of the ancient master-mason and master-architect, able to correct a mistake, however trifling, without fear of contravening a specification written some time previously, or the fear of an arbitration following on at the hands of a contractor who did not quite see eye to eye with himself. It would be interesting and instructive to know the cost per cubic yard of the Thirlmere masonry dam—that was the facing, the "plums," and the concrete which formed the matrix of those plums; and the cost of the Vyrnwy wall without any of the accessories—the wall faced and hearted with that Cyclopean rubble.

Sir Benjamin Baker. Sir BENJAMIN BAKER, K.C.M.G., President, said no doubt Mr. Deacon would state that the cost of the masonry was not uniform throughout the dam; and probably Mr. Hill, with his experience of disputes in connection with the Thirlmere works, would say that the cost might possibly be different after passing through the arbitrator's hands from what it was in the contractor's tender.

Sir George Barclay Bruce. Sir GEORGE BARCLAY BRUCE, Past-President, thought Mr. Binnie had been somewhat exercising his imagination and drawing a very dreary picture in what was manifestly meant to be a review of the action of the Royal Commission upon the supply of water to London. He would not enter into this in any detail, but inasmuch as utterances in that room from distinguished engineers were apt to be considered as gospel by, perhaps, an uninstructed public, even when they were very far from being a complete and proper representation of the facts of the case; it was, perhaps, fitting that the other side should be noted upon the records of the Institution. The statement referred to was that they had recently been told, on high official authority, that when supplying a few millions of people with water, it was immaterial whether in the water-supply there was mixed up the excreta of another million of people. That had been mentioned "as an important official determination." Whilst Mr. Binnie had not referred in so many words to the Report of the Royal Commission, there was no doubt that he did refer to London, and meant to convey to the people of London that they were drinking the excreta of other people. He did not think he could meet that assertion more conclusively and with more effect than by reading the opinions

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of a man who had, perhaps, been more distinguished than any other in his determination to provide pure water for the inhabitants of these islands; he referred to Dr. Edward Frankland, who might be called the apostle of pure water, and who had striven in every way for years—before most engineers thought about it—to provide such pure water and to draw the attention of the public to its necessity. Dr. Frankland had said, in a lecture on the water-supply of London, delivered at the Royal Institution[1] in February last, "In conclusion, I have shown that the Thames basin can furnish an ample supply for fifty or more years to come, whilst the quality of the spring and deep-well water and of the filtered river-water would be unimpeachable. To secure these benefits for the future, storage must be gradually provided for 11,500 millions of gallons of water, judiciously selected in the Thames Valley, and a proportionate volume in the basin of the Lea; whilst filtration must be carried to its utmost perfection by the use of finer sand than is at present employed, and by the maintenance of a uniform rate during the twenty-four hours. There is nothing heroic in laying pipes along the banks of the Thames, or even in making reservoirs in the Thames basin. They do not appeal to the imagination like that colossal work the bringing of water to Birmingham from the mountains of Wales, and there is little in such a scheme to recommend it to the mind of the ambitious engineers of to-day. Nevertheless, by means of storage, by utilizing springs, by sinking deep wells, and by such comparatively simple means, there is, in my opinion, every reason to congratulate ourselves that for half a century at least we have at our doors, so to speak, an ample supply of water, which for palatability, wholesomeness and general excellence, will not be surpassed by any supply in the world." That was the utterance of a scientific man of vast experience, who was perfectly disinterested in what he said, and could estimate as well as any man living the truth of the statement upon which he risked his character and his fame. Sir George Barclay Bruce.

Prof. W. C. Unwin had just returned from Westmoreland, where the largest works of the Manchester supply had been erected. In saying a word about the first of the two Papers, containing an account of so many ingenious mechanical arrangements, he noted how completely, under the smoothing action of vegetation, the pipe line and the conduit line, which three years ago exhibited a most fearful gash in the hill-side, had disappeared; so that without close investigation it was impossible to distinguish either the pipe Prof. Unwin.

[1] This lecture, in pamphlet form, is in the Library Inst. C.E.

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Prof. Unwin. line or the conduit line. Thirlmere never looked so well as at the present time, though when drawn down for the supply of Manchester its appearance might not be so satisfactory.

Through the kindness of Mr. Deacon he had had from time to time opportunities of seeing the progress of the great work at Vyrnwy, from the period when the original glaciated surface of the old valley was exposed. It was in its way the most remarkable masonry work in the world, and he doubted if any work constructed in masonry so nearly approached to a homogeneous, solid, coherent structure. An ingenious arrangement for economising in the cost of pipe line, by reducing the section of the water-stream at the necessary valves, had been spoken of by Mr. Deacon as involving a loss of head which could be afforded in most cases. Two or three years ago he had had an opportunity of seeing one of the Venturi meters placed on a pipe line, 48 inches in diameter, through which water was passing at about 5 or 6 feet per second. In the Venturi meter the section of water-stream was reduced to one-twentieth of the area of the pipe, and on a wooden tower alongside the pipe line there were placed three glass tubes carried to a height of 50 or 60 feet, which showed the exact pressure of water before entering the meter, at the contracted section and where the pipe again became of full diameter. The whole loss of head in passing through the meter was only something like 3 inches, so that, if the contraction were made in the proper way, it was obvious that the loss of head was an insignificant quantity. One of the finest works along the line of supply from Vyrnwy was the Norton Water Tower, as to which he should like to say a word. Mr. Deacon was possibly deceived as to the date at which tanks with spherical bottoms were first used. Dupuit published, in 1860 or 1864, in his book on Waterworks, a description of a reservoir at Chaillot, in which there was an iron tank 65 feet in diameter, with a spherical bottom—the thrust or pull at the angle between the cylindrical side and the spherical bottom being taken by a very large and solid I-shaped cast-iron ring. In the tank at Norton the size was larger, and the arrangements for taking up the thrust were exceedingly ingenious. As to the dam, in the course of the discussion Mr. Charles Hawksley had stated that, by calculation, the stability of the dam was such that it had a factor of safety of 2. He was very glad that Mr. Hawksley introduced the condition "by calculation," for of course that was the result of a calculation which depended upon assumptions so wide of the truth, that the result was absolutely fictitious and misleading. It assumed full water-pressure on the whole height of the up-stream

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side of the dam, and neglected the earth-pressure on the down-stream side. It assumed what he thought an exaggerated amount of water-pressure under the base of the dam; and, far worse, it assumed that one could treat the dam, for the purpose of a theory of overturning, as a mere vertical slice. That was widely wrong for a dam of varying height with a curved down-stream edge. If the real factor of safety of that dam against overturning could be calculated, it would be more nearly equal to 10 than to 2. It was because the French engineers perceived so clearly the erroneousness of the assumptions on which the ordinary theory of overturning of dams was made, that they abandoned it and took refuge in the calculation of the stress in the dam. So long as a dam was completely in compression, if adequately low compressive stresses were secured, then the dam was also safe against overturning. Twice during the discussion reference had been made to the failure a year ago of the dam at Bouzey, near Epinal. Unless he was much mistaken, the final failure of that dam was the first and only case on record of a high dam failing by overturning. He saw the dam not very long after it had failed, and a great deal of information about the structure was furnished by the courteous engineer at the works. As it touched upon a question of considerable importance in the construction of dams, he should like to indicate briefly what he thought happened in that case. It had been said that the design of the dam was bad, though it was not said in what respect; and also that it had a bad foundation. That was something like the mayor of a town in France who had seventeen reasons for not firing a royal salute, and the first was that there was no powder. If the design of the dam was bad, there was no need to adduce a bad foundation, and to mix up those two things was, he thought, to obscure completely the causes of the most instructive accident which had happened to a purely masonry structure within engineering knowledge. The history of the dam was illustrated by *Fig. 3*. As long ago as 1884 a portion of the dam slipped on the foundation—there was no doubt about that. A length of 450 feet slipped forward on the base, the greatest versed sine of the curve being 12 inches. During the slip, at exactly those portions of the masonry where the tension due to bending would be greatest, vertical cracks appeared. These were shown in *Figs. 3* at *a*, *a*, *a*. Nobody knew how far those cracks went into the dam, but they probably were very large. He did not believe there was any reason whatever for thinking that those vertical cracks in any material way weakened the dam to resist the water-pressure to which it was exposed. To repair the accident of 1884, the engineer

Prof. Unwin.

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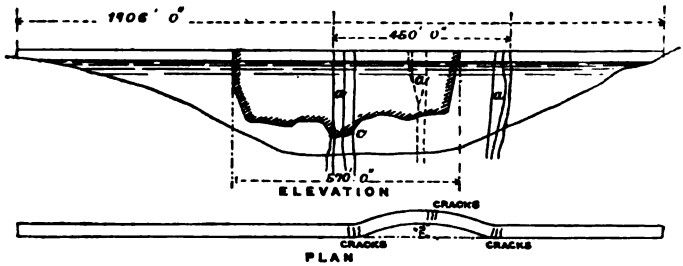
Prof. Unwin. had to resort to the expedient of building up to a certain height a strong counterfort, *b*, *Fig. 4*, extending for a considerable length of the dam. As far as he could see, that repair of the dam was successful, for in the accident of last year the counterfort had in

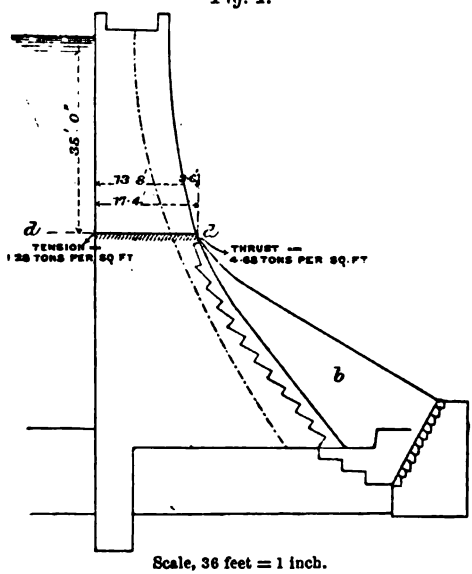
*Figs. 3.*




Scale, 550 feet = 1 inch.

BOUZEY DAM—LONGITUDINAL SECTION.

*Fig. 4.*




Scale, 36 feet = 1 inch.

BOUZEY DAM—CROSS SECTION.

no way been disturbed. A tiny bit at the top had been torn off in the rush of the materials over the dam, but the repair after 1884 was complete so far as the cause of the accident of that year was concerned. No further slip on the foundation had

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occurred, and he was unable to see that the earlier accident had any relation in the way of cause or contributory damage to the accident which occurred last year. In the later accident there was torn out of the dam a nearly rectangular piece about 570 feet in length, *Fig. 3*. The break occurred just above the top of the counterfort. The part of the dam which gave way was in no way helped by the counterfort, but was above it. The ends of the break seemed to intentionally avoid the vertical cracks of the previous accident in 1884, only at *c* there was a gap which nearly coincided with one of the sets of cracks of 1884. The cracks were exactly at the point of the water side of the dam where, in the accident of last year, the dam would be chiefly in compression from horizontal bending of the displaced portion. They would, therefore, not directly weaken the dam. Looking for some cause of the recent accident, it appeared that the dam was not built of very good materials, but of such as might well have made a substantial and satisfactory dam. The density of the masonry was low—only a little more than 2; and taking that density and drawing the line of resistance of the dam, it was found to lie in its proper position—as some engineers thought—within the middle third of the thickness of the dam most of the way. But exactly at the level of the fracture *d d*, *Fig. 4*, it was a long way out of the middle third; at that point the line of resistance approached within 3½ feet of the down-stream face of the dam. With a homogeneous mass of masonry, the water side of the dam must have been subjected at that point to tension. Calculation showed that in that condition of the dam there would be 1¼ ton per square foot of tension on the upstream face of the dam, and 4⅝ tons of compression on the down-stream edge. It was known that a very poor cement had been used, and the resistance both of the stone and mortar to tension was small. Suppose for a moment that the dam at some part of its water-face at that level was unable to resist the tension of 1¼ ton per square foot. What would happen then would be that a horizontal fissure would be formed, which, to relieve the tension, would extend in for a distance of 6½ feet. When the fissure had extended in the 6½ feet, *Fig. 5*, the whole of the tension in that section of the dam would be released, and the whole section would then be in compression, and if no new force arose to destroy it, the wall would reassume a perfectly stable condition. The compression on the down-stream edge would only be increased to 5½ tons per square foot; and in that condition the wall, supposing no new force were to come in, would be in a perfectly satisfactory condition. If it

Prof. Unwin.

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Prof. Unwin. had been a retaining-wall with earth at the back of it, he did not think the horizontal fissure would have sensibly weakened it. Unfortunately, in the case of a dam supporting water-pressure, a new force would come into operation. When a fissure was formed on the water surface of the wall, the water entered the fissure, and a large upward-acting, overturning pressure was brought into operation in the fissure, *Fig. 6*, which again disturbed the stability of the dam at that section. Under these new conditions, the water-pressure would create a tension of $3\frac{1}{2}$ tons at that point of the dam, and a compression of something like $7\frac{3}{4}$ tons at the down-stream edge. Under those conditions the horizontal fissuring would go on, and if only a vertical slice of the dam was considered, the failure would have occurred there, in consequence

*Fig. 5.*

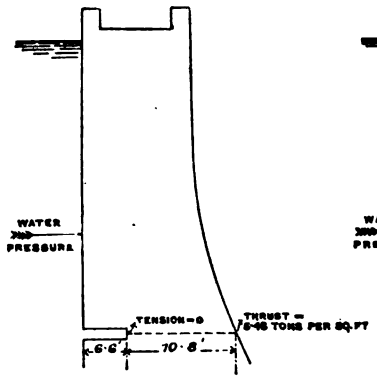
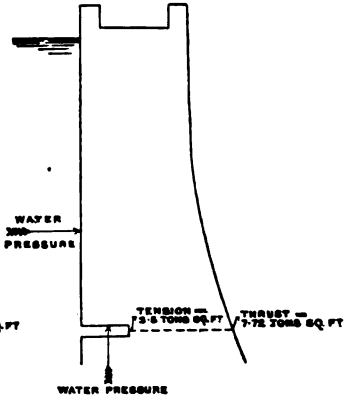



*Fig. 6.*




Scale, 24 feet = 1 inch.

of the progressive development of the fissure, soon after the horizontal fissuring began. What had further to be explained was how the dam stood for fourteen or fifteen years. Professor Unwin imagined that some horizontal fissuring began at a very early date, but the dam did not fail for a long period. The reason why, with that horizontal fissure, the dam could still stand, was that it did not consist of a series of vertical slices, but that every vertical slice was connected at the ends with the stable part beyond it, and that the horizontal fissure must have extended a very long way, probably 500 feet, over the length of the dam before the overturning moment, due to the horizontal water-pressure and the upward pressure in the fissure, was capable, not only of overturning this rectangular lump, but of breaking

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through the dam at its vertical sections at the ends. As the fissure progressed horizontally in the plane of greatest tension, the overturning upward pressure in the fissure would increase. When the fissure had extended so far that the horizontal pressure on the water-face and the upward pressure in the fissure together were sufficient not only to overturn a block of masonry more than 500 feet in length, but at the same time to break through two vertical sections of the dam 35 feet in height at the ends, then the failure would occur. He had alluded to this because, in all the theories of overturning it was quite clear that speaking of the dam as a mere series of vertical slices was an extremely erroneous supposition. He had no doubt that there never had been before a dam constructed of so stable a character as that at Vyrnwy. Prof. Unwin.

Mr. G. FARREN wished to make a few remarks upon the French dams, although he had been somewhat anticipated by Professor Unwin who had given information of a most instructive kind. He would direct attention to a drawing of the Bouzey dam, contrasted with the Furens dam, superposed on the same diagram, *Fig. 7*. The Bouzey dam had stood for a long time, but no one could say that it was typical of French engineering. He should be sorry if an impression went forth that English engineers imagined that the French engineers were not reliable in the designs of dams. The dam had previously given signs of distress, though the water was not up to the intended level. He had shown where the dam had been strengthened by the hatched portion, *Fig. 8*. After that operation, as Professor Unwin had described, straight vertical fissures appeared, and after a time some one in authority, he did not know who, said the water might be allowed to rise to the proper level of the dam, and some time afterwards the dam failed. He had marked the lines of pressure on the Bouzey dam, *Fig. 8*, and, on considering this section, anyone would see that what was supposed might happen did actually happen—the dam gave way at the very point where, if there was any truth in mathematical theory, it should have given way—exactly at the point where the tension was greatest on the inner face, and where the line of stress on the outer face largely departed from the middle third. The failure of the Bouzey dam afforded a splendid illustration of the truth of the data that the French and some English engineers had worked upon. Mr. Farren.

He had stood in the Valley d'Enfer and had seen the Furens dam. He had also inspected the Chartrain dam, *Fig. 9*, which was the most recent and highest type of French design. It was the deepest and largest dam in the world—he did not mean as far as length

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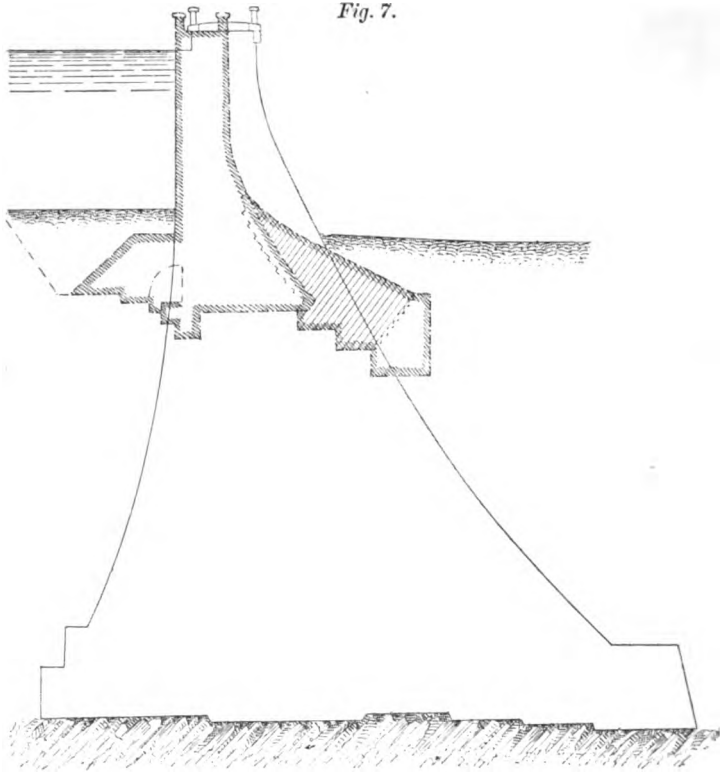
Mr. Farren. was concerned. French engineers were rather dissatisfied with the tightness of their dams. In the Chartrain dam, what was called a "chemise," $\frac{3}{4}$ inch in thickness, of cement was put in. This was left alone for five hours, and the water allowed to rise; and so it remained, the whole setting under water. The Furens dam, when he saw it, was not as tight as he had expected a dam

*Fig. 7.*



BOUZEY DAM AND FURENS DAM COMPARED.

of that kind to be. He was also much astonished at the small quantity of water in the reservoir, it being not more than one-third full. He would like to ask what would be the difference in the level of the water when the Vyrnwy dam was doing its full work.

He would direct attention to a comparison of a dam designed by English mathematical methods, drawn on the same *Fig.* as the

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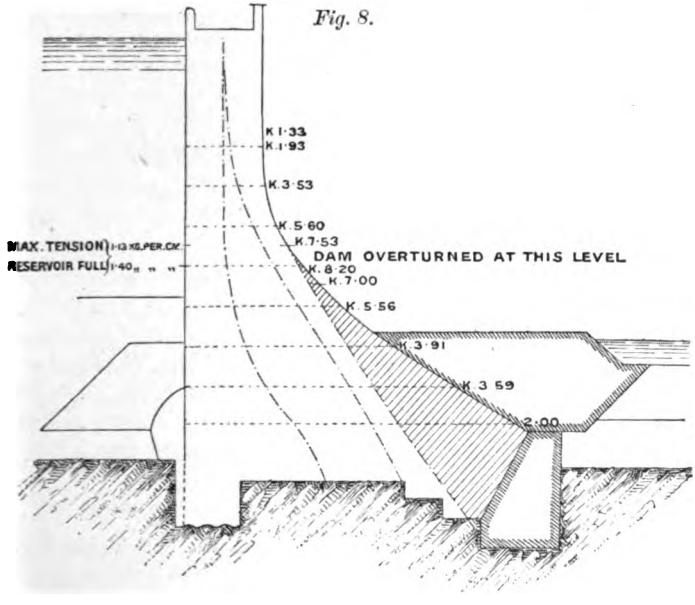
Chartrain dam, with the latter, supposing the stresses upon the two dams to be the same, and the concurrence between them was perfectly remarkable. Anyone taking an interest in such dams could readily find all the calculations for a dam of that kind.[1] There was one other consideration to be drawn from these dams, viz., that they not only showed which was the best form, but also how to dispose of the material, and therefore necessarily the cheapest form of dam. He would like to have seen some of the dams that had been referred to a little more in accordance with

Mr. Farren.

*Fig. 8.*




Scale, $\frac{1}{200}$.

CROSS-SECTION OF BOUZEY DAM.

that scientific theory, because they could not go far wrong when it was found that French and English engineers' designs on the same data so entirely concurred. No doubt the engineers would be able to give good authority for their departure from that theoretical design.

Some sixteen or seventeen years ago, when Mr. Farren first began to take an interest in these questions, he went to the Vyrnwy

[1] Minutes of Proceedings Inst. C.E., vol. cxv. pp. 120 and 180.



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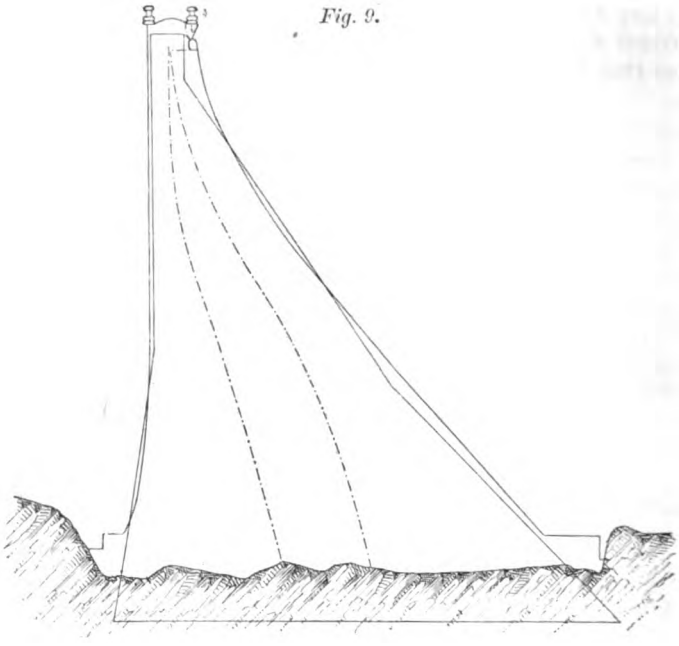
Mr. Farren. Valley, and there stayed in a house which was now some twelve fathoms below water, and there Mr. Deacon was at work upon the preliminaries of the undertaking in question. At that time Mr. Deacon's name was the only one mentioned in connection with this great scheme, and it was owing to that meeting and to the

*Fig. 9.*



CHARTRAIN DAM COMPARED WITH SECTION BY CALCULATION.

courtesy by which Mr. Farren was allowed from time to time to witness the progress of the work that he became acquainted with the matter.

Dr. Pole. Dr. POLE, Honorary Secretary, said that, having frequently had to do with the water-supply of Manchester and of Liverpool, he had watched the progress of the works described in the two Papers before the meeting, and he could say nothing but praise in regard to them. But, considering the magnificent nature of these two undertakings, he thought a little more might be said as to their early history; and as he had personally taken a part in this, he would venture to add some particulars. The fine water sources here utilized were first brought into notice about thirty years ago. The water-supply of the

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metropolis had frequently attracted attention, and, an impression having gained ground that it was objectionable on principle to use, for human consumption, water drawn from the River Thames, some proposals were published for abandoning the present sources, and for supplying the metropolis on the gravitation system from hilly districts a long distance away. The most prominent of these schemes were, one by Mr. Bateman to bring water from the sources of the Severn in North and Mid Wales, and another, by Messrs. Hemans and Hassard, to resort to the lakes of Cumberland and Westmoreland. These proposals, from the grandeur of their character and the eminence of the engineers from whom they emanated, made such an impression on the public that the Government thought it worth while to appoint, in December 1866, a Royal Commission under the Presidency of the Duke of Richmond, in order to examine them. The engineers on the Commission were Colonel Harness, R.E., and Mr. Thomas E. Harrison (who was afterwards President of this Institution). Shortly after the Commission had commenced their work, Dr. Pole was also engaged to give engineering aid, and he was subsequently appointed Secretary. The first step of the Commission was to call the promoters of the principal new schemes as witnesses, and to obtain from them full information as to their designs. Mr. Bateman described his plan at great length, furnishing drawings and other data. He proposed to take the upper drainage grounds of two rivers forming the most northerly tributaries to the Severn, called the Vyrnwy and the Banw, constructing on the former a large reservoir (this part of his plan being now utilized for Liverpool), and to these he added another district, lying more to the south, including several tributary streams rising on the east of Plinlimmon, reservoirs being formed thereon in suitable places. The waters from these two districts were to converge at a point near Montgomery, whence they were to be conveyed to London; the total length of conduit from the junction being a little over 180 miles. The total drainage area marked out was 204 square miles, and the storage was about 6,710 million cubic feet. The estimated cost was £11,400,000. The plan proposed by Messrs. Hemans and Hassard was to obtain water from the high lands of the Cumberland and Westmoreland Lake District, and to utilize as storing reservoirs the three great lakes, Thirlmere, Ullswater, and Haweswater. These were to have their water-levels raised, and were to be connected together by conduits and tunnels, the water being delivered from the south end of Ullswater to London by a conduit 270 miles long. The total drainage area Dr. Pole.



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Dr. Pole. was to be 230 square miles; the whole available storage about 5,563 million cubic feet; and the estimated cost £13,500,000.[1] Having taken the evidence of the promoters, the Commission obtained opinions on the schemes from many eminent hydraulic engineers and other experts, and they then determined to procure further information by independent inquiries of their own. For this purpose they deputed Dr. Pole to make a personal examination of the various districts, which he carried out during the summer of 1867. His instructions were to collect samples of water which should fairly represent the various sources; and to note down any observations on points affecting the schemes generally, such as the nature of the ground, the manufactures, mineral workings, and so on. The samples of water were carefully analysed by Messrs. Frankland and Odling, and full particulars of the whole information so gained were published by the Commission.[2] As the chief motive for these schemes was to supply London, the Commissioners felt bound also to investigate generally the state of the Metropolitan water-supply, and full powers to do this were granted them by a new Royal Warrant in April, 1867. This investigation ultimately proved their most important business, and it was in regard to this object that their work had become most generally known. They arrived at the conclusion that no such large changes were necessary; but this did not prevent them from giving the new schemes a thorough examination, and the plans for them were described and discussed with almost as much fullness as if their adoption had been recommended. On finishing their work, the Commission did Dr. Pole the honour of confiding to him the preparation of their Report, which was presented in June, 1869, and had subsequently become, he believed, well known in water-works history. The opinions it contained regarding the proposals for new sources of supply were, on the whole, very favourable. The Commission declared that both the principal schemes were feasible and practicable, and that large supplies of pure water might be obtained by them. And they discussed, with care and impartiality various objections that had been brought forward. They also alluded prominently to the possibility of these sources being utilized for other places nearer to them than

[1] Another scheme for supplying London from the upper sources of the River Wye in Mid-Wales was also laid before the Commission by Mr. Hamilton Fulton; and this has lately been partially utilized for the supply of Birmingham.—W. P.

[2] Appendix to the Minutes of Evidence before the Royal Commission on Water Supply, 1869.

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London, as the following quotation (Report, par. 53) would show:— Dr. Pole.

"There is no doubt that the Lake district is a very fine gathering ground for soft water; but it is deserving of consideration that this district is not unlikely to be claimed as the most natural source of supply for large and increasing manufacturing populations in the north of England, for whom soft water would be particularly valuable; and we hold it to be erroneous in principle that any one town or district should take possession of a gathering ground geographically belonging to another, unless it can be clearly shown that circumstances render such a step justifiable."

It was certain that the publicity given by the Duke of Richmond's Commission to the consideration of these large sources of water-supply tended materially to encourage and facilitate their utilization, and it was on this account that Dr. Pole had ventured to lay these few remarks before the Institution in connection with the two important and able Papers under discussion.

Mr. W. Amor was interested by a remark made by Mr. Symons as to the remarkable approximations arrived at with regard to rainfall in localities where records were not available. Many of the members would doubtless be very grateful if Mr. Symons would give some information as to how he arrived at those approximations. No doubt the following words would be familiar to most engineers—"There does not yet exist any theory from which a probable estimate of the rainfall in a given district can be deduced independently of direct observation." These words were written about a quarter of a century ago, and any addition to the means of ascertaining the rainfall would, he was sure, be gratefully received by engineers. Mr. Amor.

Mr. E. Sandeman said the discussion on the Papers had been of great interest to him, as he was engaged in building a reservoir on Dartmoor, one of the dams of which was of masonry, and measured from the ground-line to the crest 77 feet in height, and from the foundation to the overflow, 129 feet. The building of the two dams under consideration raised a very important question, viz., whether it was more advantageous to build masonry dams with wet or what might be termed dry concrete. He preferred concrete mixed in a wet state for works requiring watertight construction; first, because wet concrete was not inferior to dry; secondly, that it was safer in use; and thirdly, it did not require so much labour in ramming, and therefore cost less. With reference to the first point, it would have been most instructive to have had an opportunity of comparing the weight of the Thirlmere concrete, in relation to the rock of which it was made, with the Mr. Sandeman.

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Mr. Sandeman. results obtained at Vyrnwy. His experience did not bear out the idea that a greater density was obtained by mixing concrete in a more than ordinarily dry state and subjecting it to considerable ramming. The Dartmoor granite that he was using for concrete weighed 165 lbs. per cubic foot, and the concrete made from it weighed 151⅓ lbs., or 91·7 per cent. of the weight of the solid granite. That concrete, gauged 5 to 1, was laid in a fairly wet condition and rammed. The concrete he had used in a fairly dry condition, and on which much labour had been expended in ramming, weighed only 147 lbs. per cubic foot, or 89·1 per cent. of the solid granite. The percentage obtained at Vyrnwy was, from the figures given, between 91·1 and 93·5. In order to make an accurate comparison it would be necessary to know the proportions of the stone and cement in each case. He did not know whether Mr. Deacon had carried out any experiment with wet concrete; if so the result would be useful for comparison. His second point, that it was safer to use concrete in a wet than in a dry state, was, he understood, the experience of many engineers; and with regard to the third point, that it was cheaper, there could be no doubt.

Mr. Deacon. Mr. G. F. DEACON said, in explanation, he had never stated that he used concrete in a dry, or nearly dry, condition; he merely said that when it was so saturated that one could see the water on the surface before it was rammed, ramming did no further good. Supersaturated concrete was an incompressible material, and the only effect of ramming was to bring the cement to the surface, which was harmful. His experience was that the water must be so far limited that it could only be brought to the surface by ramming, and then—subject to the ingredients being properly proportioned—if the concrete began to shake like a jelly, water-tightness was secured.

Mr. Cooper. Mr. C. H. COOPER wished to direct attention to the jointing of the pipes. Full details of the joint had been given by Mr. Hill, but unfortunately no mention was made of the diameter of the pipes to which each joint referred. Mr. Cooper had in his mind a main, laid in 1890, of 42 inches diameter; he walked a few days ago over about three-quarters of a mile of the main and counted no less than twelve leaky joints. The length of the sockets in the main was 4½ inches, and a quarter of an inch was allowed for the thickness of the lead in the joint. The joints were run in solid with lead, a steel band being placed inside to prevent the lead from running through the joint. It was said some two or three years ago that leaks appeared in the main in question on account

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of expansion and contraction. Expansion rings were put in, but did not seem in any way to improve the main, which leaked as much as before the rings were inserted. He would like to ask if there was any considerable number of leaks in the Thirlmere main. Mr. Cooper.

Mr. D. B. Butler, referring to the question of concrete, said Mr. Deacon appeared to have applied to actual work the well-known maxim of testing-room practice, viz., that the minimum of water gave the best results. Of course in actual practice there were several essential conditions, which were not the same as in the testing-room. For instance, in gauging cement for testing purposes, a non-porous mould and a non-porous bed were used, so that there was no fear of any of the water being extracted after gauging; whereas in practice if the aggregate were porous, or if by any means the water necessary for the proper setting of the cement were extracted, its strength was materially affected. It was well known that the less water used the quicker the cement set, and if by chance the cement was quick-setting and it was rammed after setting had commenced, its setting properties were practically destroyed. He would like to ask for particulars of the analysis of the cement used and of the tensile strains at longer dates. The average tensile strain at seven days was given as 709 lbs. per square inch, which was certainly very high. At another place what might be called the "marmalade-pot" experiments was referred to, by which the rise in temperature during setting was ascertained, and it was assumed that, if the cement showed no increase in temperature, it contained no free lime. He thought the rise in temperature was due to the chemical action of setting, as he had always found that the quicker the cement set the greater would be the rise in temperature. He did not think it was due to free lime. He had known more than one case in which a quick-setting cement heated sensibly to the touch in a very few minutes, and yet was perfectly sound. He had some figures showing the increase of temperature in setting, which he had taken from the late Mr. Henry Faija's test-books of some fourteen years ago. As an example, one cement was found to increase as much as 15° F. in fourteen minutes and was set hard in an hour; while in another case, there was no increase of temperature, and the sample was not set in six or seven hours. When speaking of being set, he meant that no indentation could be made by the pressure of the thumb-nail. He congratulated Mr. Deacon on the method adopted for maturing the cement, and thought that if those precautions were always taken failures in cement work would rarely be heard of. Mr. Butler.

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Sir Guilford Molesworth.

Sir GUILFORD MOLESWORTH said the calculations of Messrs. Graeff and Delocre had been referred to, but, as he had mentioned on a former occasion,[1] the formulas of those gentlemen, though correct as far as pressure on the dam was concerned when the reservoir was empty, were wanting considerably in the case of a full reservoir, as they only represented the vertical component and not full pressure. Anyone who had read Mr. Bouvier's minute[2] on the subject would see how much the actual stress was in excess of that calculated as coming upon the dam when the reservoir was full. In some cases in which he had made calculations on Mr. Bouvier's formulas he found the actual stress as much as 40 per cent. greater than that which was calculated by Messrs. Graeff and Delocre. That was a very important difference. He agreed with what the President had said on a former occasion, that it was very undesirable to dogmatize too much with regard to the "middle third." It had been distinctly shown by Professor Unwin that there was danger incurred by going much out of the middle third and too close to the edge; but Rankine had only said that "the lines of resistance should lie within, or but a small distance beyond, the middle third of the wall." He was recently consulted in the case of a dam about 100 feet in height and 70 feet thick at the base. By calculation the line of pressure came 4 inches outside the middle third, and the Government Department of the Colony made it a condition that it must be altered to come well within the middle third. He thought that was rather an unnecessary refinement. In a discussion in 1893, Sir Benjamin Baker,[3] speaking with regard to some diagrams showing the stress on dams in which Sir Guilford Molesworth had calculated the limit of pressure to a decimal of a ton per square foot, rightly observed that though practical men would understand that such a refinement was unnecessary, yet young engineers might be misled by it. Of course his object in calculating to the decimal of a ton was to compare with the calculations which had been made by the French engineers in kilogrammes per square centimetre, and in that way the decimals came in; but he quite agreed that such a refinement was unnecessary where the strains were of so uncertain a character. He would, with permission, read a note[4] he made in reporting on the subject to the Government of India some thirteen years ago. "The difference between the results of the formulæ of Mr. Bouvier

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 84.
[2] Annales des Ponts et Chaussées, vol. x., 1875.
[3] Minutes of Proceedings Inst. C.E., vol. cxv. p. 109.
[4] "Note on High Masonry Dams," p. 2. Roorkee, 1883.

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and those of his predecessors is a matter of considerable importance, for in some calculations which I have made I have found the pressure indicated by the former to be more than 40 per cent. in excess of that indicated by the latter, and there is no doubt that the theory of Mr. Bouvier is correct according to the present state of experimental science, for there exists some uncertainty in the problem of pressure in structures of this character." Rankine,[1] writing on the subject of high dams, remarked:—"The assumption on which the rule is based, of an uniform rate of variation of that component of the pressure which is normal to the pressed surface, and is known to be sensibly correct in the case of beams, and is probably very near the truth in walls of uniform or nearly uniform thickness. Whether, or to what extent, it deviates from exactness in walls of varying thickness, is uncertain in the present state of our experimental knowledge." Again Mr. Bresse, who is considered a high authority in France, remarks, "In certain cases there may be different modes of drawing a comparison between a solid mass of masonry and a prism, and we should thus be led to consider several neutral axes. Take, for example, a reservoir wall which we may assume, for the sake of simplicity, to be a rectangular parallelopiped, and having two horizontal and four vertical faces. This wall . . . will be a solid body loaded transversely and exposed to a cross bending stress. On the other hand, if the horizontal planes be taken as normal sections, each section would support an inclined force, the resultant of the water pressure, and the gravity exerted on that portion above the plane in question. We might imagine a crowd of similar examples. What, then, is the line which should be taken as the neutral axis, when considering the conditions of stability? This is a special question which it would be difficult to define in a general way, and in answering which the perception of the engineer will often be his guide." On this Sir Guilford Molesworth remarked[2] in his Report, "It is obvious then that, in consideration of the existence of such uncertainties, the approximate formula, covered as it is by a large factor of safety, is sufficiently accurate for all practical purposes, and coinciding as it does very closely with such theory as we are able to evolve from the present state of experimental knowledge, any further refinements would appear to be practically unnecessary." In the French dams, which were made with good hydraulic lime and not with cement, the

Sir Guilford Molesworth.

[1] "Professional Papers on Indian Engineering," Second Series, vol. ii. p. 91. Roorkee, 1873.

[2] "Note on High Masonry Dams," p. 3. Roorkee, 1883.

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Sir Guilford Molesworth

density was about 147 lbs. per cubic foot. A fine specimen, stated to be 160 lbs. per cubic foot, had been exhibited by Mr. Mansergh. It was, he thought, impossible to get a more dense or magnificent stone concrete than that. The practical limits of density must vary between about 135 lbs. and 160 lbs. per cubic foot. The limits of pressure in the Ternay dam were calculated by the formulas of Messrs. Graeffe and Delocre at 6·4 tons to the square foot; but Mr. Bouvier showed, according to the theory which had been advanced, an actual pressure of 8¼ tons. In the Dam de Ban the calculated pressure was 7·3 tons and the actual pressure upwards of 9 tons; fortunately the character of the concrete was so excellent that the work was quite safe even under this increase of pressure. Mr. Bouvier estimated, that after ten years, when the lime had had time to consolidate and set thoroughly, attaining its extreme hardness, a pressure of 12 tons per square foot might be safely borne by this concrete. It was instructive to note that Mr. Bouvier had made experiments on the crushing stress necessary to destroy the concrete. Of course the usual test conditions were very different from the actual conditions which were borne in the dam. In the first place the tests were generally made with small cubes, whereas the material in the dam was confined on all sides, and naturally bore much more. On the other hand, the setting in a small test-block took place much more rapidly than when it was confined in the heart of a dam and without access to the air. The experiments made by Mr. Bouvier were on cubes two and a half years old, isolated without any support at the sides, and he found, as a rule, they crushed at about 91 tons per square foot. When confined with blocks of wood, and cardboard between, so as to give some sort of lateral support, they averaged about 137 tons per square foot, and in one instance the specimen confined was not crushed until 166 tons pressure per square foot was attained. He was glad to see that great cleanliness had been observed in making one of the dams, to free the stones from anything like dirt or loam. He had sometimes found amongst engineers great laxity in using dirty water with cement; if there were any clayey particles, it was very apt to kill the cement—or at all events to prevent its adherence, or setting to its normal condition. He should be much inclined, in a dam of that sort, to use moderately small stones that would go into the concrete-mixer; and after thoroughly washing all the gravel and sand that might pass into the concrete-mixer, to mix all well together, so that stones might be intimately mixed with the cement. He had known dams faced with masonry on both sides with intermediate concrete filling. That was essen-

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tially a faulty principle, because there might be a difference in the settlement between the outside and the inside work; and he should much prefer that the work should be of a thoroughly homogeneous character throughout. Sir Guilford Molesworth.

Sir BENJAMIN BAKER, President, said he thought engineers had shown characteristic coolness in the way in which they had conducted the discussion. Even the apparent difference between the Chief Engineer of the London County Council and one of the Royal Commissioners on Water Supply was, he believed, more a matter of sentiment than of fact, because they looked at things from a different point of view. With regard to the Bouzey dam, engineers throughout the world, of course, were agreed that the difficulty was to show why it should have stood so long and not why it failed. Professor Unwin had demonstrated the fact of its weakness, as other engineers had done throughout Europe, and as any one could have done independently in a variety of ways, but had been unable to demonstrate why it had not failed long ago. The real puzzle was, how it occurred that admittedly able and mathematically qualified French engineers should have allowed it to pass, because many of them must have seen it during the thirteen years, and yet none of them drew a diagram, like Professor Unwin had done after the event, and said, "You see this dam must fail." Sir Benjamin Baker.

Mr. G. H. HILL, in reply, took the question raised by Mr. Vernon-Harcourt as an enquiry as to what had been the effect of the raising of the Thirlmere lake upon the scenery of the country of the lake district. Down to the present time there had been very little occasion to withdraw any large quantity of water from the lake, and therefore the rise and fall of the water had not been sufficient to test that point. The natural rise and fall of the lake before the works were constructed was about 6 feet, and it had scarcely varied more than 2 feet from that since the work was finished. His impression was that it would not make much difference in the scenery, though of course all storage was created for the purpose of being drawn off in dry seasons. The very object of the storage was such, that no one could expect the lake to be kept full; but still, when the water was withdrawn to any great extent, in consequence of the character of the country being particularly rocky and disintegrated, he did not think there would be any objectionable appearance. There was a fine new road along the west side of the lake. With regard to the concrete used for the aqueduct in the Lake district, it was made principally from "sammel," which was found on the surface of the rock. This was a material which was used for Mr. Hill.

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Mr. Hill. building in the district. He took samples of it and had it tested by being put together with broken stone in the ordinary way of making concrete, and he found that a most excellent concrete was obtained. There was a sample on the table showing a piece cut out of a wall 15 inches thick in the "cut-and-cover" portion of the aqueduct. For the dam itself at the outlet of the lake the concrete was made by the grinding of the Silurian rock and by the use of large stones, called "plums" by the people who used them, and by others "displacers." All these were bedded upon cement mortar, and placed at such distances apart that the men could easily get round to make a first class job when filling in. The concrete used was mixed with water. It was not dry concrete, and it was not soaked with water, but still there was sufficient water. He had been making concrete for thirty years, and found that in cases of that sort a better result was obtained by using the spade on edge in putting the concrete into its place, than by ramming too much, which brought the fine material to the top. The object really was to keep the fine material intermixed with the stone below. In several cases he had known failures to take place, not from the proportions being wrong in the concrete, but from carelessness in putting it together. That was to say, the stone had got into one place and the fine material into another, instead of their being intimately mixed together. Where care was taken in putting it in, he had not the slightest doubt a solid structure would be obtained. At Thirlmere the "plums," as they were called, varied between ½ ton and 4 tons in weight, but there was no stone in the district for the facing of the dam. The men found that after two or three hours had been spent in dressing the stone it frequently went to pieces. The consequence was that millstone grit-rock had to be brought from near Preston for facing the inside of the dam, and red sandstone from Annan in Dumfriesshire for the outside. With regard to the pipe joints, he might say that there were 44½ miles of pipes, 40 inches in diameter, and with the exception of a few joints at first which were found to leak, since the time the works were opened eighteen months ago he had not heard of a single blown or leaky joint. There had been two burst pipes, and in those cases the automatic valves on the pipe-line came into operation, and shut off the water, and no mischief was done. Automatic arrangements were very well in their way, but they must be kept in order, or they could not be depended upon. He had put large quantities of concrete into deep trenches, where reservoirs were made as a foundation for the puddle wall,

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in some cases subject to 150 feet of pressure. At that time the concrete was made, except in very wet places, from lias lime of 4 to 1 and 3 to 1, and he did not know a single instance where the water had found its way through, though the concrete was but about 8 feet thick. With regard to the effect of the copper-wire gauze, the water was admitted from the lake into the straining-well, as shown in Fig. 6, Plate 2. For the first two or three months, when the water was withdrawn from the lake, a large quantity of vegetable matter reached the face of the strainers, the wire gauze of which was 900 meshes to a square inch, and there was some little trouble. Afterwards a certain quantity of fine material passed through the meshes. It went down the aqueduct, but as there were scouring valves at frequent intervals along the aqueduct, any little accumulation could be got rid of. When the water reached Manchester through the 96 miles of aqueduct, it went into the service-reservoir, which was constructed for equalising the draught through the twenty-four hours in the city. Upon leaving that reservoir it went through strainers again before delivery to the city. Mr. Hill.

He should have been glad to give the cost per cubic yard of the dam, but unfortunately as the contractors had not yet been settled with, he was unable to say what the final determination would be, although he had a very good idea. He believed Manchester possessed a fine piece of work, and that it had been executed at less cost than would have been the case if it had been contracted for. He was doing a great quantity of work at the present time by administration where no contractor intervened; and it could be done pretty cheaply if it was well looked after, but the difficulty was to get proper superintendence for the work. On the line of the aqueduct there were at one time 112 inspectors, and there were never less than three on the dam. Nothing was put in that was not thoroughly inspected. All the stone used in the dam was washed, and not a single particle of dirt was allowed to go into the mixture forming the concrete.

Mr. G. F. Deacon proposed to reply upon the discussion in the order of his Paper. To the history of the undertaking Mr. Charles Hawksley had contributed certain items. It was much easier to speak of the part taken in any important work by a father deservedly respected, than to speak of one's own share in such a work. Some statements however compelled him, much against his will, to add a few facts. After the scheme had received Parliamentary sanction, Mr. Deacon was appointed under the seal of the Corporation as joint engineer with the late Mr. Hawksley, which Mr. Deacon.

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Mr. Deacon. position he held till Mr. Hawksley's retirement referred to in the Paper. During that period the working drawings were jointly signed, as the deposited plans had been, with the two names bracketed together as the engineers, and the specifications were similarly backed. Those who were curious as to these matters would find them set out in great detail in a report dated 12th October, 1885, prepared, with the assistance of the Town Clerk, by the then Chairman of the Liverpool Water Committee, who had been associated with the undertaking from its inception. That report was published in the proceedings of the Town Council of Liverpool. Almost exactly one-half the work was completed under the former administration, and included a large portion of the cast-iron pipes and pipe-laying, while the remaining half, including many of the more difficult portions, was carried out under the later administration.

In reference to Mr. Charles Hawksley's observations concerning the Vyrnwy dam, he desired to say that as originally designed the dam was about 8 feet thinner than as carried out, and had already been shown in profile in the Minutes of Proceedings, vol. cxv. page 113, by the line of long dots in *Fig. 9*. The section even of this thinner dam was somewhat stronger than Mr. Deacon thought necessary; but after full discussion he signed the drawing in the office of Mr. Hawksley, who made with his pen a bracket to link the two names together. This drawing was submitted to and approved by the Council on the 1st of June, 1881. He could not subsequently concur in the expediency of giving the dam the greatly-increased strength afterwards proposed; but nevertheless, to avoid serious differences, he signed the subsequent drawings also. When Mr. Hawksley retired part of one of the 15-feet culverts had been put in; it was therefore too late to change the base up to the level of those culverts. However a comparison of the superstructure as carried out with the drawings signed by Mr. Hawksley and himself would show that, as soon as possible, he reduced the section of the main work and entirely altered the superstructure. He concurred with what Professor Unwin had said on the subject. The factor of safety of the Vyrnwy dam was a great deal more than 2. No one however could say what the actual factor was in such a case, and he therefore regarded this kind of investigation as futile. He had already said that he concurred in the desire to prevent the possibility of uplift from intrusive water, and he did prevent it, as shown at *Fig. 3*, page 30; but there were no conceivable circumstances—even if water leaking from the rock had been sealed down instead

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of being relieved—in which the uplift could approach that assumed in the calculations given in Table IV, p. 78. Moreover it was easy to show that many existing dams regarded as perfectly safe had much less than half the factor of safety—if that term must be used—of the Vyrnwy dam, and it followed therefore that if the factor of the Vyrnwy dam did not exceed 2, those other dams must have perished. Masonry dams had, he believed, always been designed as if the material had no tensile strength, and this, in the absence of better knowledge of the tensile strength of large masses of masonry in general, and of the exact method of construction of the particular masses under consideration, could scarcely be objected to; but was it logical, in speaking of factors of safety, to omit all consideration of tensile strength? Why should a masonry dam be the only structure in which no credit was given for that element of strength? Consider the case of two masonry dams A and B. Suppose A to be sufficiently strong notwithstanding that the tensile strength of the materials was low, and suppose B to be the same in every respect as A, except that the materials had twice the tensile strength of those in A. The method of Table IV would give both those dams the same factor of safety, though the latter might withstand twice the lateral pressure required to overturn the former! In considering factors of safety the holding down by tension could no more be neglected than the pressing down by gravity, though the structure might be made sufficiently strong to stand without that additional help. The greatest load on the base of the Vyrnwy dam due to gravity did not exceed 6½ tons per square foot, and this load was at the inner toe and tended to hold the structure down against overturning; but the adhesion to the rock and the cohesion of the materials of the dam certainly exceeded 8 tons per square foot, so that the resistance to overturning due to tension was actually greater than the resistance to overturning due to gravity. Referring to the diagram exhibited, he observed that the specific gravity of the Vyrnwy dam had been taken at 2·23, but the density of the dam as constructed was about 17 per cent. greater. The ruins of the Bouzey masonry dam near Epinal, which he had visited in company with Professor Unwin, were most instructive, and afforded, so far as he knew, the only example of a masonry dam which had proved itself to have a factor of safety of about unity against overturning. It seemed to him certain that nothing but the cohesion of the masonry of that dam was competent to account for the fact that it had stood for thirteen years. It did this however, and therefore in the ordinary acceptation of the words "factor of safety" it certainly

Mr. Deacon.

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Mr. Deacon. had a factor of one. Let any one compare its section with that of the Vyrnwy dam; and the density of its masonry, 1·8 to 1·9,[1] with the density of the Vyrnwy masonry, 2·595, and it would be found that the factor of safety of the Vyrnwy dam, assuming the materials to be no stronger than those of the Bouzey dam, was about 3·7. Then take the Vyrnwy tensile strength of more than 8 tons per square foot, and that of the Bouzey dam, which he thought could not be put higher than 1 ton or at most 2 tons per square foot, and the conclusion would be inevitable that any calculation which brought out a factor of safety of only 2 for the Vyrnwy dam could have no practical application or utility.

Concrete, masonry, and cement were the next subjects of discussion. The densities and weights of the principal materials of the Vyrnwy dam were:

| | Density (dry). | Weight (dry). |
|---|---|---|
| | | Lbs. per Cub. Ft. |
| Rock . . . . . | 2·721 | 170 |
| Concrete between stones . . . . . | 2·52 | 157 |
| Masonry (mean of the whole dam) . . . . | 2·595 | 162 |

He had been asked whether he had made comparative experiments with fresh concrete absolutely saturated with water, so that the water could at first be seen, and with concrete similarly made, but not saturated, in which the water was only rendered visible by ramming. He had frequently made such experiments, and on a very large scale. The result was, as it clearly must be, a greater density in the case of the comparatively dry concrete. Indeed, it was incontrovertible that so far as the volume of the water exceeded the volume of the dry interstices of the consolidated work, it must increase those interstices, and so reduce the density; and the spaces occupied by such excess of water formed so many ducts for the future passage of water under pressure. The only use of an excess of water beyond the small quantity required for chemical combination of the ingredients, was to act as a lubricator, and thus to facilitate motion of the particles under

[1] The samples of the materials he had collected from the ruins of the Bouzey dam had the following densities: red sandstone, 1·97; white sandstone, 1·943; mortar, 1·588. Assuming the mortar to be one-third of the whole, this would give a mean density of only 1·829 or 114·13 lbs. per cubic foot as compared with 162 lbs. per cubic foot in the case of the Vyrnwy dam. These were the densities of the dry materials. If saturated throughout the density of the whole structure would be increased to 2·07 or 129·17 lbs. per cubic foot.—G. F. D.

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the rammer in the process of consolidation. So far as was necessary for this purpose he employed an excess of water; but the moment the demand for such lubrication was exceeded, the attainment of maximum density was rendered more difficult. He ventured to say that these could not be mere matters of opinion, as they were matters of obvious and ascertained fact, and in the whole discussion he found no statement of facts tending in the slightest degree to controvert them. On the other hand, if it were needful, he could point to instances of extensive concrete works intended to be watertight, in which he believed every precaution had been adopted except this one, and those works were not impervious to a few feet of water. The cost of the necessary ramming in relation to the cost of the work was insignificant, and he had found that the difficulty of supervision was actually reduced, because the necessary jelly-like condition, and the appearance of water at the surface, were perfectly definite phenomena, the attainment of which the men themselves showed little or no tendency to shirk. The experiments of Mr. Sandeman could not, he thought, have been made under similar conditions, or the results described would not have been attained. It was not sufficient to try such experiments by ramming into small boxes; in order to produce the necessary shaking a considerable mass was necessary. Several speakers had referred to the advantages of initially saturated concrete, but not one had ventured to say that it was watertight under high pressure, and not a single example of a successful trial of the watertightness of such concrete had been given. He had pointed to the complete success, in respect of density and watertightness, of the Vyrnwy dam in which the concrete was not initially saturated; and better still—because the result could be more exactly determined—of the culvert 705 yards long, shown at *Fig. 9*, page 44, formed with a thickness of only 18 inches of such concrete gauged 6 to 1, which, as he had already stated, was impervious under a head of 56 feet of water. Then in reference to the strength of such concrete, he had drawn attention, near the foot of page 43, to what he believed to be the unsurpassed strength of the blocks cut from the interior of the Vyrnwy dam. It had not, in the whole course of the discussion, been suggested that such results as these could be obtained from supersaturated concrete, though excellent specimens of concrete made with an excess of water were placed on the table. Such concrete was valuable in its proper place, but he ventured to think that no experienced hydraulic engineer would expect to find it quite watertight under a pressure of 50 feet of water, much less under 100 feet or 150 feet. Whilst Mr. Mansergh had spoken

Mr. Deacon.



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Mr. Deacon. eulogistically of the Vyrnwy dam, he seemed to think that the comparatively dry method of construction must have been costly. This was certainly not so. Strength for strength, he had found the Vyrnwy method to be the cheapest, and the actual excess of cost due to ramming the joints of the masonry did not exceed 6*d.* or 8*d.* per cubic yard. He thought much misapprehension concerning this matter arose from the fact that some speakers had not differentiated between the conditions necessary for bearing purposes and those necessary for watertightness. For bearing purposes, great density was not necessary unless great strength was required, and the concrete might be put in wet; for watertightness it could not be dispensed with, and the little extra cost of obtaining it by ramming, until the water, in comparatively dry concrete, just appeared at the surface, and the jelly-like consistency indicating incompressibility was obtained, must be incurred. He knew very well the excellent concrete work in the Liverpool docks; but it had never been suggested that this work was watertight. It was not necessary that it should be so. In reply to the question whether the weight of the Vyrnwy concrete had been determined from a block cut out of the solid wall, as in such case it might be in great part solid stone, the various blocks weighed were cut out of the solid wall, but no parts of the building stones they joined were included when they were weighed. The concrete so weighed was, in fact, such concrete as lay on the table. He scarcely thought the height of a masonry dam could be properly measured in the manner adopted by Mr. Mansergh, who, in comparing the short dams of the Birmingham work with the Vyrnwy dam measured only from the river level. So measured, the Vyrnwy dam would be the lowest, whereas it was actually 34 feet higher than the highest of the others, and this greater height extended over several hundred feet of length. The strength of such dams as those of Furens and Gorzente, and those in the Birmingham work could not be compared with that of the Vyrnwy dam by any examination of the cross section alone. The latter dams were in narrow wedge-like valleys, and derived great support from the side rock. There was nothing new in the temperature test he adopted for determining the condition of Portland cement in respect of the absence of free or loosely combined lime, as other engineers had found it equally successful. The heat produced by the slaking of this lime had been confused with the heat produced in the process of setting of quick-setting cement, which was quite unsuitable for hydraulic works of the kind in question. In the slow-setting cements properly employed in such works, the heat

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produced in the process of setting was insignificant, and would rarely raise the thermometer by more than 2° or 3° F.; and this process of setting did not begin till after the thermometric determination of the presence of free or loosely combined lime had been completed. Most careful engineers had for twenty-five years or thirty years been in the habit of watching pats of cement kept under water to discover if hair cracks were developed, and more recently the steam bath and other methods had been introduced to hasten the development of the cracks. It would be found however that the simpler thermometer test was sufficient, and that any cement which had been so aerated as to pass that test would show no hair cracks, and (other proper tests being complied with) was perfectly safe. For hydraulic work the manufacturer must supply cement of the prescribed strength and fineness; but it was rarely attempted to impose upon him the duty of bringing it into condition for immediate use. Wherever possible, that should be done at the works by exposure and turning over in the usual manner, or, better still, in some such manner as that described at page 45. All good qualities of the cement were at their maximum at and about the time at which it passed the temperature test; and if aeration on the shelves, or otherwise, were continued much beyond that time, the strength of the cement would slowly decrease. For this reason, on the Vyrnwy works great care was taken to turn the movable shelves once a day, or once in two or three days, as might be necessary to bring the material into its best condition at the time it was likely to be required for use; and, notwithstanding the great quantity of cement employed and the irregular nature of the work owing to bad weather and other causes, no difficulty arose in fulfilling this condition. In very dry weather the process was hastened by providing vapour from spray or from large surfaces of water maintained in the cement store; and he had found a large shallow pan with a lamp under it, built around to enclose the heat, an effective way of moistening the air and thus bringing the cement into proper condition without deterioration of strength. The old belief that cement concrete should be placed *in sitú* immediately it was made had been referred to. This belief had no doubt arisen from the fact that the earlier Portland cements were generally quick setting. With slow-setting cement, such as was alone suitable for the works under consideration, this was not so. He had fully discussed the limitations of the matter at pages 12 and 13, vol. lviii. of the Minutes of Proceedings. In connection with this subject of materials for masonry dam construction, he desired to repeat that notwithstanding the remarkable

Mr. Deacon.



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Mr. Deacon. results, in point both of strength and of watertightness, which had been attained with Portland cement, he was satisfied that many of the natural hydraulic limes gave at least equally good results if manipulated in an appropriate manner. For particular purposes—as for instance in contact with running water or where the full strength of the work was required to be brought into play shortly after the concrete or mortar were used—Portland cement had obvious advantages. But these advantages seemed to him to have led engineers too generally to neglect the cheaper material. For more than two years he had been engaged in an attempt to make up the arrears of exact knowledge in connection with the treatment of lime concrete and mortar. It was a large subject which could not be dealt with here, and he would only say that he had arrived at conditions which enabled him to use natural hydraulic limes for the structures in question with the same sense of security as Portland cement. He felt no less confidence as to the result. The material was easier to work, there were no hair cracks, there was no greater expansion or contraction from changes of temperature, no necessity for avoiding disturbance of work done during the previous day or two days, the watertightness was at least as perfect, the strength, after the first year, was not inferior, and the cost was very much less. He was at present carrying out two masonry dams in which Portland cement was only used where running water could not be avoided, the rest of the work being cemented with natural hydraulic lime.

With regard to the straining arrangements in the Vyrnwy Tower, the cause of the puncturing of the copper-wire gauze which had been referred to, and which had been successfully remedied, was described at pages 54 and 55 of the Paper. Moreover, on page 51 it was stated why the signal which was arranged to be given when the difference of head within and without the strainer reached 1½ inch was not now used. No signal was required when it was found that a strainer should be cleansed daily. The straining effected by this fine gauze greatly exceeded in efficiency any straining he had found elsewhere, and the machinery for lifting, washing and replacing the straining cylinders had worked perfectly from the beginning. As to the sand filters at Oswestry, it seemed to be implied by Mr. Beloe that in consequence of certain defects "large additional filter-beds were in course of construction." The facts were that in 1885 he designed twelve filter-beds for the whole 40 million gallons a day, and one third of these—that is four filter-beds—were intended to be used for the present instalment of 13⅓ millions. It was at that time not accurately known what

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rate of filtration would be suitable in all seasons for the Vyrnwy water, and for reasons of economy the construction of the fourth filter of the first instalment was deferred. But he had taken the precaution of putting in foundations for it below certain made ground in order that it might be quickly constructed when actually needed. It was this fourth filter-bed that was now being constructed, and this seemed to have called forth the remark that "large additional filter-beds" were in course of construction, as if they were for the purpose of superseding some previous construction. This filter-bed was divided down the middle, in order that a smaller portion of the whole area should be out of work when a bed was being cleansed. Where four filter-beds instead of twelve were used, it was clearly advantageous to divide them. Whilst the differences between the Rivington and the Vyrnwy filters had been alluded to, no information was given about the matter. The late Mr. Hawksley had been in the habit of relaying with a layer of clean sand, the layer of foul sand scraped from the surface of a filter-bed before the filter was again used, and at Rivington, as elsewhere, he naturally placed the washing apparatus as close to the filter as possible. In many filter-beds he placed that apparatus in the middle of the bed, and it was proposed by him, while acting with Mr. Deacon, to place it there in the case of the Vyrnwy filters. In designing those filters Mr. Deacon's original intention was to adopt the old method of replacing the layers as they were removed, and in order to reduce the labour to a minimum he placed the sand washer in the centre of each filter. About the time of the construction of these filters a marked advance in the knowledge of sand filtration had taken place. Bacteriological investigation had shown that efficient sand filtration depended almost entirely upon the surface film, and that the thickness of the bed of sand had very little to do with the matter. It became perfectly clear that the substitution of a thin layer of clean sand for the layer removed for washing practically threw the filters out of efficient use for some days after each change. Even the removal of a layer without adding new sand was harmful, but upon the undisturbed sand below, the surface film became much more rapidly efficient, than upon a comparatively loose layer of clean sand. He had therefore ever since, in common, he believed, with most recent practice, reduced the number and importance of the changes to a minimum by simply scraping off the surface film on each occasion when cleansing was required, and removing it to a sand store, where, exposed to the weather, it would soon acquire a condition in which it could be more efficiently washed. This involved scraping down the

Mr. Deacon.

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Mr. Deacon. sand to a much reduced thickness. Both at Rivington and at the filter-beds on the Vyrnwy aqueduct the change to this method had been made with great advantage. The fact that the efficiency of filtration was greatest when the filter-bed was oldest and consequently thinnest showed conclusively that efficiency had little or no connection with the thickness of the bed. It was clear that such a change of method, involving the entire removal of perhaps half the depth of sand from the filter-bed before making up the bed again with clean sand, rendered washing in the centres of the beds inconvenient, and at the Vyrnwy filters a change in this respect would probably be beneficial. The present Water Engineer of Liverpool, Mr. Parry, had in progress a long and exact examination from day to day of the results of filtration as affected by these and other considerations, and he hoped the Institution would secure for publication in the Proceedings the very valuable results thus obtained. No remarks had been made upon the striking difference between the water-supply of Liverpool strained through gauze with 10,000 meshes to the square inch and afterwards filtered in the most perfect manner, and that of Manchester strained through gauze with 900 meshes to the square inch and not filtered at all. There was no important difference between the Vyrnwy and the Thirlmere water, and he believed both were perfectly wholesome without filtration of any kind; but it was certain that the Liverpool people, accustomed as they had been for nearly fifty years to the filtered water from Rivington, and to the pure sandstone water of the public wells, would not be satisfied with any surface water delivered in its crude condition.

As the crossing of the Weaver had been described in previous publications in considerable detail,[1] he thought sufficient space was occupied with the matter. Under a misapprehension Mr. Wells had stated in effect that as the pipe had to pass under a very much larger navigation close by, viz. the Manchester Ship Canal, it was decided by the Board of Trade, to whom the matter was referred, that the pipes should be sunk, as Mr. Deacon had proposed, in the soft bed, and so far it had answered perfectly. The proximity of the Manchester Ship Canal crossing, more than 6 miles distant, and upon a different siphon, was not an element in the decision; and the bed dredged out for the purpose of sinking the pipes was not a soft one, but consisted largely of the New Red Marls. The Board of Trade accepted Mr. Deacon's views rather than those of the Weaver Navigation

[1] See footnote, *ante*, p. 61.

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Commissioners, and had they acted as wisely in connection with the crossing under the Mersey, where the bed was soft, they would have deprived him of the pleasure of bringing to a successful issue the aqueduct tunnel under the Mersey—a work which was generally said to be impossible—and they would have saved the Corporation of Liverpool a large sum of money. The next work on the aqueduct, the Norton Tower, had been referred to. Until Professor Unwin had directed his attention to it, he had not heard of the Chaillot tank; and he had believed the German towers referred to in the "Zeitschrift des Vereines deutscher Ingenieure" in 1886 to have been the earliest examples of this type of tank. He found the tank of the Chaillot tower contained 200,000 gallons, or 250,000 gallons at a height of 30 feet as compared with 650,000 gallons in the case of the Norton tank at a height of 113 feet. Mr. Deacon.

The tunnel under the Mersey had been referred to by Mr. Wolfe Barry who asked why he "did not adopt the plan of passing the aqueduct under the Mersey in the solid rock, in preference to taking it through the alluvial deposit." The question was readily answered by reference to the section of the strata in *Fig. 38*, and by a comparison of the original estimate for carrying the tunnel through the rock with the actual cost of constructing it at the higher level. The late Mr. Hawksley had desired to avoid the loose materials beneath the River Mersey by making a tunnel in the sandstone rock, and for that purpose to sink at one side of the river to a depth of 174 feet and at the other to a depth of 104 feet. The borings and the adjoining aqueduct crossing under the Manchester Ship Canal led Mr. Deacon to believe that 104 feet on the Cheshire side would have been insufficient. However at these depths (see *Fig. 10*, next page) Mr. Hawksley had estimated the cost of the tunnel as a little over £79,000. The actual cost of the tunnel as constructed was under £35,000, including the steel pipes, pumping-machinery, and all accessories. That however did not include the cost of the first attempt, and of the lamentable law suit and arbitration to which it led. The whole cost of that first attempt, including the legal proceedings, was £24,000, which, added to the £35,000, brought up the total cost of failure and success to £59,000 —or £20,000 less than the mere estimate for the tunnel through the rock. But these figures did not express the full advantage of the course actually adopted. The sandstone, like the alluvium, was full of water, and, at the great depth of 175 feet, it had not been contemplated to make the tunnel watertight (though subsequent experience led him to think it could be done) and expensive pumping-machinery would therefore have had to be

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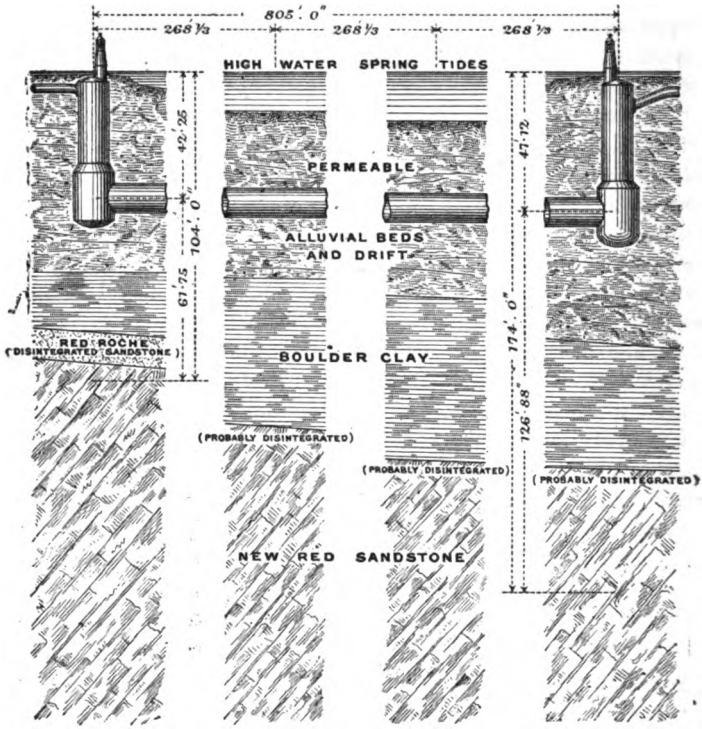
Mr. Deacon. provided and maintained. The tunnel actually constructed was watertight, and the little hydraulic pumping-engine was worked by the water in the Vyrnwy main and only came into operation at distant intervals and for a few minutes at a time, when from condensation on the cold walls of the tunnel or otherwise the sump became charged with water. The cause of failure of the original attempt to tunnel through the boulder clay had been referred to at

*Fig. 10.*




Scale, 1 inch = 64 feet.

VYRNWY TUNNEL UNDER RIVER MERSEY.

page 65 of the Paper; and after the success he had subsequently attained, he was justified in saying with every confidence that if the precautions prescribed in his specification had been taken from the beginning, the law suit and arbitration would have been avoided and the whole work would have been completed for less than £40,000. As constructed, the pressure upon the Vyrnwy siphon was 363 feet; while in the sandstone scheme it would have

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Mr. Deacon.

been about 490 feet, a serious though not impracticable pressure for such large mains. The lightening of the load by 127 feet was, however, without doubt a thing to be desired.

The rainfall on the Vyrnwy area had been determined by no less than thirty gauges. The rainfall towards the western boundary of the area was approximately 50 per cent. higher than that near the eastern boundary, and over the whole drainage area of 23,200 acres, which the Corporation had power to intercept, the mean fall during the decade ending 1891 had been about 68 inches.

Objection had been made to the use of Latin for certain inscriptions on the Vyrnwy works, but he could not concur in that objection, still less could he concur in the view that, if there were to be one uniform language, Latin would be the best. There would not long be much of the Latin left; and the objection that Latin was not the language of any living generation seemed a good reason for using it where a record for all time was to be maintained. In simple dignity moreover a correct Latin inscription was unsurpassed and unsurpassable. The day might yet be far distant when that traveller from New Zealand—whom Macaulay had made immortal—should "in the midst of a vast solitude take his stand on a broken arch of London Bridge to sketch the ruins of St. Paul's." But when it came would he be satisfied with sketching ancient London? Would he not also visit the great aqueducts of the north? And if he did, could there be any doubt that inscriptions in the language of Augustus would be more intelligible to him than any records in the long-forgotten tongue spoken by Englishmen of the Victorian era?

## Correspondence.

Mr. Griffith.

Mr. Percy Griffith observed that the capacity of the Manchester Waterworks, previous to the carrying out of the Thirlmere scheme, was given as 25,000,000 gallons per day, and that of the new works as 50,000,000 gallons per day, or a total of 75,000,000 gallons. Allowing 25 gallons per head per day, the old works could thus supply a population of 1,000,000, the new works 2,000,000, a total of 3,000,000. The cost of the former was given as £3,150,000, including service-reservoirs and distributing-mains; and that of the latter as £4,400,000, or a total of £7,550,000. The rates per head of population provided for were thus—

| | £ | s. | d. |
|---|---|---|---|
| Old works | 3 | 3 | 0 |
| Thirlmere scheme | 2 | 0 | 5 |
| Average | 2 | 10 | 4 |

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Mr. Griffith. From statistics relating to small waterworks, which he had recently collected, it appeared that the average cost of complete works rarely exceeded £2 per head of population provided for, and excluding service-reservoirs and distributing-mains, the average cost was about £1 per head. As the question of cost was often a vital one in the comparison of impounding with pumping systems or underground supplies, he thought some explanation of the high cost of the Thirlmere scheme, namely, £2 0*s.* 5*d.* per head, would be valuable. It would also be interesting to know whether this rate might be taken as an average for impounding schemes. The total cost of the Vyrnwy scheme had not been given, but the available supply of 40,000,000 gallons per day was (at 25 gallons per head) sufficient for a population of 1,600,000. An approximation to the total cost, so that the rate per head could be calculated, would be of interest.

Major Scott-Moncrieff. Major G. K. SCOTT-MONCRIEFF was at a loss whether to admire more the moral courage with which the construction of colossal works, described in Mr. Deacon's Paper, had been undertaken on principles hitherto untried, in this country at least, or the care with which each detail has been organised so as to ensure the practical translation into actual work of the principles in question. He desired to record his admiration of the way in which not only the works had been designed, but of the way in which each subsequent step had been made thoroughly secure by testing, by care in the selection and in the use of the materials, utilizing them in the manner indicated by theory and experiment, though not, it might be, in accordance with trade customs. In his present capacity as an Instructor at the School of Military Engineering, he was fortunate enough to have the opportunity of visiting large works under construction in various parts of the country. To one who had carried out works in India there was perhaps nothing in English engineering practice that was more striking than the difference that usually obtained in the two countries in the treatment of concrete. In England the concrete was usually mixed with so much water that ramming, or consolidation other than that afforded by the working of a spade, or the trampling of working navvies, was impossible. Generally the explanation given was that any ramming was injurious to the setting of the concrete. Sometimes it was said that the result of the ramming would be to bring the moisture to the surface, and leave the lower portions of the layer without any cement. Such objections were calculated to lead to the consideration whether, after all, the other method of treatment might not be wrong. Yet, when such works as the

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Vyrnwy were visited and the result witnessed of a treatment based upon obtaining the greatest density possible with artificial means, no doubt was left as to the soundness of the methods adopted. It might at once be admitted that with contract working it was difficult to insist upon proper manipulation. This was not only because the labour per unit of work was greater, but because the actual material used per unit of completed, and therefore measured, work was much greater when consolidation by ramming was carried out. Certainly 15 per cent. more aggregate was required. This pointed to the conclusion that, in making trial investigations as to the proper ratios of matrix and aggregate, the latter should not be measured loosely in a box, but should be laid in layers and rammed tight dry before any water was poured in for the purpose of ascertaining the voids. The extra materials and labour per unit of volume thus expended made the work more expensive, and with unimportant work it might be unnecessary; but in all cases where strength, stability, or watertightness were in any way involved, he thought, in view of the striking example of Vyrnwy, there could be no doubt as to the superiority of this method over that usually adopted. As to the objection that the layers were not homogeneous, examination of the sections, as well as the remarkable results of the specific gravity, quoted by Mr. Deacon, of the concrete from the drainage well, were a sufficient answer. This was quite in accord with the experience of others who had adopted the method of consolidation described in the Paper. Major Scott-Moncrieff.

The simple test for the presence of free lime in the cement was, so far as he knew, novel. The usual test was not very satisfactory, and, with some such test as that proposed, the tests also for weight and specific gravity might be dispensed with. The method with which the cement was stored was another notable instance of care in a matter too often neglected and of the greatest practical importance. It was not stated, however, whether any tests of the quickness of setting, with the Vicat needle or otherwise, had been made. This appeared a matter of importance in connection with the length of time that ramming might be permitted, as well as the time that should not be exceeded between the mixing and the deposition *in situ*.

The care with which the disadvantages of temporary cessations were reduced to a minimum was also most instructive. Many engineers, no doubt, had had, as he sometimes had, to work without cessation for weeks, without any Sunday rests, sometimes by night as well as by day, in order to prevent the deterioration to the work that cessation would produce. Such constant work

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Major Scott-Moncrieff. was good for neither mind nor body, and any procedure which would relieve such continuous strain, while providing for the excellence of the work, should be welcomed with satisfaction.

Mr. Hill. Mr. G. H. HILL, in reply to the Correspondence, remarked that the cost per head for any waterworks depended so much upon the circumstances of each case, such as the distance the water had to be brought, the natural configuration of the sites for reservoirs, and the geological formation, as well as upon other matters, that it was impossible to lay down any rule of general application as a guide in arriving at the cost per head.

Mr. Deacon Mr. DEACON observed, in reply, that Mr. Percy Griffith appeared to have omitted from the figure of £1 per head, which he gave as the cost of small waterworks, exclusive of service reservoirs and distributing mains, the capitalized cost of working and maintaining the pumping stations upon which they were dependent, and which must be added before any accurate comparison could be made between gravitation and pumping works. It was no doubt true, however, that pumping schemes, favourably situated, were cheaper than impounding schemes, mainly for the reason that while pumping schemes often had their sources close to the population to be supplied, impounding schemes involved aqueducts of more or less considerable length; but there was no such difference in favour of pumping as the two to one which Mr. Griffith's figures would suggest. The Vyrnwy aqueduct, like the Thirlmere aqueduct, was yet incomplete for the full quantity of water which Lake Vyrnwy would yield. At the present time the Vyrnwy aqueduct would supply 13,000,000 gallons to 14,000,000 gallons a day, and the cost had been about £2,300,000, but the next two equal instalments would probably be carried out for about £800,000 each.

In reference to Major G. K. Scott-Moncrieff's observations, where the aggregate of any intended concrete consisted (as he usually endeavoured to make it consist) of broken stone, and of the same stone pulverized, the method of filling the voids with water to ascertain their volume might be superseded by direct determination of relative density by weighing the stone before and after breaking. This test of relative density he always required to be made from time to time, the sizes of materials in the dry aggregate being so proportioned that the closest approach possible to the weight of the solid rock was attained. The volume of cement or lime required to produce, under the rammer, a jelly-like consistency, and consequent watertightness would then be a minimum, but would always somewhat exceed the volume necessary to fill the voids so measured. The use of the Vicat needle

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had been referred to in a Paper which he had communicated to the Institution many years ago.[1] Cement which would bear the temperature-test he had referred to at p. 47, was necessarily slow-setting and the additional trial with the Vicat needle was not found necessary. Moreover, the conditions imposed in connection with the ramming of the concrete prevented any harmful effect, as would appear from the following considerations:—Unless the ratios of aggregate and matrix were suitable, and unless the cement was slow-setting, no amount of ramming would produce the jelly-like consistency; but in the alternative, that condition was rapidly produced after the first few inches of concrete had been laid, and when it was produced, there was no necessity for further ramming without new concrete. When a surface had attained to the proper consistency it shook like a quicksand and the shovel-men scattered more concrete thinly over it. Ramming then proceeded until the new work partook of the condition already assumed by the old, and so the work was built up. It was entirely a mistake to suppose that much labour in ramming was necessary. If the proportions of the materials were proper the labour was small, and the sufficiency of ramming was always immediately attested by the production of the very easily recognised condition of a jelly. It was not necessary or desirable to carry on the ramming until that condition disappeared, but while it freely continued, ramming had no harmful effect. Mr. Deacon.

[1] Minutes of Proceedings Inst. C.E., vol. lviii. p. 9.

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## SPECIAL GENERAL MEETING.

15 April, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

THE following Notice convening the Meeting was taken as read:—

NOTICE IS HEREBY GIVEN that a Special General Meeting of the Corporate Members of The Institution of Civil Engineers will be held at the Institution, Great George Street, Westminster, on Wednesday, the 15th day of April, 1896, at 3.30 o'clock, for the purpose of considering the alterations of the By-laws referred to in the accompanying letter.

JAMES FORREST,
*Secretary.*

*Great George Street, Westminster.*
*7th April, 1896.*

The President, having stated that the letter mentioned, with a copy of the proposed alterations in the By-laws, had been sent to all the Corporate Members in the United Kingdom, and that in response 2,047 unqualified, and only 3 qualified assents to the action of the Council had been received:

*Moved*:—That the following alterations in the By-laws, proposed by the Council, be adopted.

Section VI. shall be intituled "Constitution of Council," in lieu of the present title.

The following shall be substituted for Regulation 1: and the first clause of Regulation 2: and Regulation 4 of Section VI.

1. The number of the Council shall be such as the Council in any year may fix for the ensuing year, provided that such number shall not be less than twenty-three or more than thirty-one inclusive in both cases of the President and Vice-Presidents, but exclusive of such of the Past Presidents, if any, as may be appointed by the Council.

The President, the four Vice-Presidents, and other members of the Council (exclusive of Past Presidents, to be appointed by the Council) shall be elected annually, and the Council, when elected for the year, may appoint any number of Past

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Presidents, not exceeding four, to be members of the Council for the same year.

2. At an Ordinary Meeting at least four weeks before the Annual General Meeting, the Council shall present a list of persons whom they nominate as suitable for the offices of President, Vice-Presidents, and other members of the Council for the ensuing year, exclusive of Past Presidents to be appointed by the Council when elected. The list shall include the names of not less than seven corporate members who have not served on the Council during the current or the preceding year, and the number of names in all shall be at least two in excess of the number of the Council to be elected. The list so presented shall be the balloting list for the annual election on the last Tuesday in May,[1] unless that Tuesday shall be Whitsun Tuesday, in which case the annual election shall take place on the first Tuesday in June.

At the Ordinary Meeting next before the Annual General Meeting the members shall choose two or more persons as Scrutineers for the purposes of the Ballot. The Balloting List shall immediately, after the Ordinary Meeting at which it has been presented by the Council, be issued to all members in the United Kingdom, and to any other member residing elsewhere, who may, in writing, request to have the list forwarded to him, and shall be returned to the Secretary, at least three days before the Annual General Meeting, in a closed envelope. The Scrutineers shall open the envelopes and count the votes and report the result at the Annual General Meeting. Any Balloting List on which a member has voted for a number either more or less than one person as President, four persons as Vice-Presidents, and the prescribed number of persons as other elected members of Council, shall be rejected by the Scrutineers.

That the following consequential alterations be made in the By-laws and Regulations, that is to say :—

In Section II., Regulation 8, the words "and other Members of the Council to be elected or nominated under the By-laws," shall be substituted for the words "and fifteen other Members of Council, being twenty persons."

[1] See second Resolution, p. 130.

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Section IX. shall be intituled "Proceedings of Council," in lieu of the present title, and Regulation 1 of the same section shall be erased.

That the following alterations be made in the By-laws :—

In Section III., Regulation 11, the words "In case the expulsion of any Member, Associate, or Honorary Member shall be judged expedient," shall be omitted, and the following words shall be substituted, "The Council shall have the right, by a majority of two-thirds of those present at a meeting of the Council, to expel from the Institution any Member or Associate who may be convicted, by a competent tribunal, of felony, embezzlement, larceny, or misdemeanour, or other offence which, in the opinion of the Council, renders him unfit to be a member; and in case the expulsion of any Member or Associate shall be judged expedient on any ground whatever."

This was seconded by Mr. J. Wolfe Barry, the Senior Vice-President, and was resolved unanimously.

The President then moved that the following alterations should be made in the By-laws in order to cause the session to commence a week earlier than at present and to end on the last Tuesday in April :—

That the last sentence of the first clause of Regulation 2, Section VI., read :—

"The List so presented shall be the Balloting List for the Annual Election on the last Tuesday of the Session."

That in Section XII., Regulations 1, 3, and 4, be erased, and the following Regulations be substituted :—

(1.) The Session of the Institution shall commence annually on the first Tuesday in November, and shall continue till the end of April, and it shall be in the power of the Council to protract the Session, if it appear advisable.

(3.) The Annual General Meeting of the Institution shall be held on the last Tuesday of the Session at eight o'clock in the evening, to receive and deliberate upon the Report of the Council on the state of the Institution, with the annual statement of the accounts, and to elect the Council and Officers for the ensuing year.

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(4.) The Ordinary Meetings shall be held on every Tuesday, during the Session, at eight o'clock in the evening, with the exception of the Tuesdays between the Tuesday previous to Christmas Eve and the second Tuesday in January, and also with the exception of Easter Tuesday; but it shall be in the power of any Ordinary Meeting, on the recommendation of the Council, to make such other exceptions as may appear advisable. No new question shall be introduced, or motion be made after ten o'clock."

The motion having been seconded by Mr. J. Wolfe Barry, was put to the meeting and carried *nem. con.*

This ended the business of the Meeting.

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## APPENDIX.

THE INSTITUTION OF CIVIL ENGINEERS,
GREAT GEORGE STREET, WESTMINSTER, S.W.
*7th April, 1896.*

DEAR SIR,—In accordance with the Resolution passed at the Special General Meeting held on the 6th February, a Petition was duly presented to Her Majesty for a Supplemental Charter, to enable the votes of Members not actually present at Meetings to be taken into account in the election of the Council, and to authorise the enlargement of the Council, and the appointment of four Past-Presidents as extra Members of the Council. The Charter has now been granted and this will necessitate an immediate alteration of certain Sections of the By-laws, which will have to be sanctioned at a Special General Meeting of Corporate Members.

The notice convening this meeting and a copy of the proposed By-laws are forwarded herewith.

These alterations have been drafted and approved by the Council in consultation with their Solicitor, Mr. Hargrove, and Mr. Phipson Beale, Q.C., and are in accord with the Supplemental Charter.

Under the proposed By-laws it will be seen that three additional Members of Council must be elected at the next Annual Meeting, and the number could be gradually increased until eleven additional Members were elected. There is a further provision that at least five vacancies must be created on the Council each year, so that a proper representation of the different branches of Engineering throughout the Empire may be ensured. There is nothing in the proposed By-laws to restrict the present right of the Corporate Members (who will now be able to record their votes by voting papers) to strike out any name on the Balloting List and substitute any other.

As under the new Rules there will be a larger number of non-resident Members of Council than at present, power has been taken in the Supplemental Charter for the appointment of four Past-Presidents to perform the same duties



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as the elected resident Members of Council, upon whom of course the bulk of the Committee work must fall.

In addition to the above matters it is proposed to consider the advisability of commencing the Session one week earlier and terminating it on the last Tuesday in April, and, if such alteration be approved at the General Meeting, to modify the By-laws accordingly.

As only a small percentage of the Members can be expected to be present at the General Meeting, I am desired by the Council to ask, if you are unable to attend, that you will express your assent to the action of the Council on the enclosed card.

Yours faithfully,

JAMES FORREST,

*Secretary.*

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21 and 28 April, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D, F.R.S., President, in the Chair.

The discussion on the Papers by Messrs. Hill and Deacon on the Water-Supplies of Manchester and of Liverpool occupied these evenings.

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5 May, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

*Member.*

JOHN D'ARTH.
WILLIAM PAUL JAMES FAWCUS.
JOHN ERNEST HARRISON.
SEYMOUR BISCOE TRITTON.
WILLIAM BUTLER WHITAKER.
CHARLES HUMPHREY WINGFIELD.

And that the following Candidates had been admitted as

*Students.*

HENRY BILLINGHURST.
CHARLES LESTOURGEON BUSHELL.
ALAN JOHN DAVIDSON.
DAVID WILSON HOOD.
FREDERICK JAMES JONES.
STANLEY HUNTER JONES.
DANIEL MACNEE.
SIDNEY RICHARD MALLINSON.
CHARLES ROGERS RUTHERGLEN.
ROBERT BEEVOR SIMMERS.
CHARLES WALTER WALES.
ALEXANDER MURDOCH WEIR.

The Candidates balloted for and duly elected were: as

*Members.*

ROSWELL EMMONS BRIGGS.
WILLIAM CRAWFORD.
GEORGE OWEN WILLIAM DUNN.
WILLIAM FOGGIN.

*Associate Members.*

ARTHUR DRAX BACON.
JOHN BARNES.
JAMES BARRON, Jun.
CHARLES FREDERIC BEKENN.
THOMAS COOPER, M.A.
FREDERICK WILLIAM CROSS.
GEORGE DAVID GRAY, B.E.
HENRY ADIN HULL.
DANIEL IRVING.
ERNEST WARD LASHMORE, Stud. Inst. C.E.
JAMES GUNSON LAWN, A.R.S.M.
SAMUEL MATHER.
HUGH MILLING.
HAROLD JOHN MONKHOUSE.
HORACE PATRICK ROBERTSON, M.E.
JAMES AINSWORTH SETTLE.
ROBERT HOLROYD SLADE, Stud. Inst. C.E.
DAVID PROSSER THOMAS.
GEORGE BRUCE TOMES.
EDWARD HENRY TYLER.
JAMES WHYTE.
WILLIAM WILSON.



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(*Paper No. 2936.*)

# "American and English Methods of Manufacturing Steel Plates." [1]

By JEREMIAH HEAD, M. Inst. C.E.

THE steel-plate [2] industry of the United States of America has not yet attained the dimensions which it has in Great Britain, where about 300,000 tons [3] are consumed per annum for shipbuilding alone, exclusive of armour-plates. In the United States, the yearly consumption for ordinary shipbuilding has so far not exceeded 36,000 tons. But there are other purposes for which steel plates are used to a much greater extent in the United States, such as the fire-boxes of locomotives, where steel of a specially mild character is almost universally employed; while in Great Britain copper has always been considered the most suitable material. In the construction of large buildings, steel is largely made use of in the United States. Frameworks supporting numerous floors are frequently erected to heights of 150 feet, and even more, before any walls are commenced; the framework, and not the walls, being relied on for strength and stability. Such structures often include a considerable quantity of plates. In the construction of overhead railways, which are becoming increasingly popular in American cities, steel plates are also largely used.

*Steel-Making Processes.*—Mild steel is made from pig-iron by the Bessemer acid, the Bessemer basic, the open-hearth acid, and the open-hearth basic processes. In the two acid processes, any phosphorus contained in the materials operated on is found in the finished product. These processes are therefore applicable only where pig- and scrap-iron can be obtained virtually free from that injurious metalloid. The two basic processes, by aid

[1] The discussion upon this communication was taken in conjunction with that upon the following one by Mr. Wellman on "Four American Rolling Mills."

[2] "Ingot-iron" is perhaps a better term, but the Author has in this Paper preferred to use the more familiar one of "steel" or "mild steel."

[3] Based on Lloyd's Returns for 1894.

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of the basic-lined vessels which alone are employed, are able to remove phosphorus, and can, therefore, make use of the more impure and cheaper qualities of pig-iron. The open-hearth acid process is practically the only one in general use in Great Britain for the manufacture of ingots for plates. The other three processes have been employed, but only to an insignificant extent. For rails and bars of various sections, the first three processes are largely used.

In the United States, the first, third and fourth methods are used for plates, and the first for rails and structural shapes. The Bessemer basic process has scarcely yet obtained a footing for any purpose. This is somewhat remarkable, in view of the fact that, on the continent of Europe, and especially in Germany, the Bessemer basic process seems to have outstripped all others for section bars; and it is steel thus produced which has of late competed so successfully with English steel and iron, not only in foreign markets where the latter formerly held a monopoly, but even in English inland cities.

The cause of these marked preferences for, or neglect of, one or more of the four processes which exist in different countries, it is not easy to determine with certainty; but it is no doubt usually due to local circumstances. Steel works on the seaboard, like most of those in Great Britain, or beside navigable rivers such as some in Germany and Belgium, are well placed for obtaining the rich and pure ores of Spain and elsewhere, which gives them an advantage in carrying on the two acid processes. Those situated inland, such as the remainder of the German works and those in the English Midland counties, are less accessible to foreign ores, and to pig-iron made from them. They are therefore obliged to make the most of the local phosphoric ores, which involve one or other of the basic processes.

Joist or H-section steel, which is now widely known on both sides of the Atlantic, is usually made in America by the Bessemer acid, in England by the open-hearth acid, and in Germany and Belgium by the Bessemer basic process. This variety in modes of arriving at the same result seems to indicate that all are good enough for at all events ordinary purposes, if sufficient care be observed. But as Bessemer ingots are not at present rolled into plates on either side of the Atlantic, except where cheapness is the only or chief consideration, the Author will, for the purposes of this Paper, assume that open-hearth furnaces alone are used.

In the northern States of America, such as Pennsylvania, Ohio and Illinois, the pig-iron forming the basis of the operations

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is almost entirely made from Lake Superior ores, brought by way of the great lakes to ports on Lakes Erie or Michigan, and thence by rail to the blast-furnaces. These ores are generally, though not uniformly, very rich in iron and very free from impurities. The resulting pig-irons are distinguished in the market as "Bessemer" if they contain less, and "non-Bessemer" if they contain more than 0·1 per cent. of phosphorus.[1] Although two qualities of pig-iron may vary but little in this respect, yet if that variation is on opposite sides of the limit, it is sufficient to make a considerable difference in the market value.

For working non-Bessemer pig-iron, and so drawing supplies from a wider market and at lower prices, basic-lined furnaces are required. Miscellaneous scrap-iron, which is usually cheap, can then be utilized; whereas with acid-lined furnaces Bessemer pig-iron and best selected scrap, which is relatively expensive, must be used. These considerations have carried such weight that one of the principal American steel-plate makers, who five years ago had only one basic-lined and seven acid-lined furnaces, has now adopted basic-linings to all. Lower carbon, silicon, sulphur and phosphorus can generally be obtained by using a basic- rather than an acid-lining, and the resulting steel is more suitable for such purposes as locomotive fire-boxes. Details are given in the Appendix.

*Open-hearth Furnaces.*—The capacity of American open-hearth steel furnaces varies between 15 tons and 50 tons, with an average yield of ten charges per week. A production of even 350 tons per week seems large, especially for a basic-lined furnace. In Great Britain, where highly phosphoric pig-iron is commonly used in basic open-hearth furnaces, the slag to be dealt with may amount to about one-third of the weight of the steel produced. Such slag, containing about 16 per cent. of phosphoric anhydride, is a very valuable by-product. But in American practice a marketable by-product has not so far been looked for or produced. The pig is not purposely phosphoretted; consequently such large basic additions are not necessary during conversion. The weight of the slag is not more than about one-fifth that of the steel produced, and nearly as heavy an output can be obtained from a basic- as from an acid-lined furnace of similar dimensions. The metallic yield, or ratio between the iron in

[1] As much as three-fourths of the production in the northern States can be classified as Bessemer pig-iron.

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the ingots and in the materials charged, is about 86 per cent. for acid, and 84 per cent. for basic furnaces.

*Natural Gas.*—In the Pittsburg district natural gas is available both for the melting- and the heating-furnaces. Containing as it does 92 per cent. by weight of combustible matter, instead of say 27½ per cent. for producer-gas,[1] and possessing over twelve times the calorific value, it gives an important advantage in command of heat. Its richness enables the regenerators to be devoted entirely to heating the air, which therefore enters the furnace at a higher temperature than usual. Natural gas is, however, much less plentiful than formerly, and the price has risen until, all things being considered, it is no longer cheaper than producer-gas.[2] Where the latter heating agent is employed, about 9 cwt. of coal are usually required per ton of ingots in acid, and 13 cwt. in basic furnaces.

*Furnace-Charging.*—In some cases the introduction of materials into the open-hearth furnaces is facilitated by a charging apparatus which travels along the furnace platform, and comprises hydraulic or pneumatic cylinders for performing the necessary operations. The most recent machines are actuated by electricity. Charging a large furnace by hand requires at least two hours, or by machines say one hour, so that there is obviously ample room for labour- and time-saving apparatus in this direction.

*Ingot-Casting.*—Steel ingots intended for plates (always excluding armour-plates) vary in weight between 10 tons and 1½ tons and even less, according to whether they are intended to be passed through a cogging-mill, or sent direct to the plate-mill. In the former case they are cast from above, in the latter case from below. The practice of bottom-casting was first devised by Mr. Richard Pink, of the Hörde Works, Germany, and was subsequently adopted at several steel works in England. It was thought to be specially adapted for plate-ingots, because, being undisturbed by pouring at the upper end, they were less likely to be spongy and unsound. It also facilitated partial filling, and so ingots could be obtained of different sizes from the same mould.

*Cogging.*—The development, and now universal adoption in Great Britain, of powerful cogging machinery, superseding the earlier practice of hammering and cutting by knives, has enabled larger ingots to be dealt with. It has minimised the ill-effects of

[1] Paper on "Fuel Gas" read by Mr. E. McMillan before the American Gas Light Association, 27th October, 1887.

[2] At present 10 cents (or 5*d.*) per 1,000 cubic feet is paid at Pittsburg for natural gas, and 65 cents (or 2*s.* 8½*d.*) per gross ton for coal.

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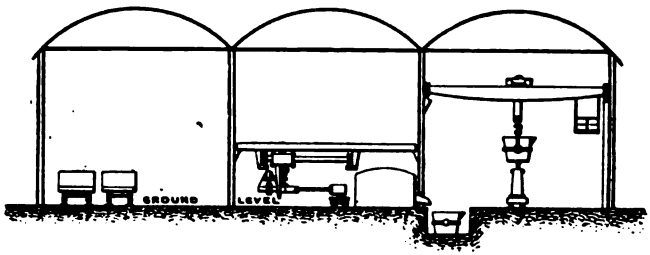
pouring from above, because the disturbed and unsound portion is smaller in proportion to the whole ingot. It has also enabled the ingots to be made of two or three standard sizes, whatever the sizes of the finished plates, thereby greatly reducing the number of moulds in use. By aid of the cogging-mill, and its necessary adjunct the hot-bloom shears, the individual pieces required for plates can be cut with greater exactness than by partial pouring in the ingot moulds, and a somewhat smaller waste in scrap is the result. It has frequently been urged in favour of the cogging-mill and the larger ingots which it renders possible, that it enables more work to be done upon the metal, and that the quality is thereby necessarily improved. An ingot 30 inches thick rolled in the cogging-mill to a slab 5 inches thick, and further reduced in the finishing-mill to a plate ½ inch thick, might be expected to

*Fig. 1.*




Scale, 1 inch = 40 feet.

TYPICAL AMERICAN STEEL MELTING-HOUSE.

give better results than a flat ingot 12 inches thick rolled in one mill to a similar finished plate. Careful tests, however, fail to reveal any marked advantage of one method over the other,[1] and experience shows that plates of excellent quality can be produced by either method.

*Melting-Houses.*—At one works only in the United States has the English practice of cogging been adopted. There the open-hearth furnaces, each of which is capable of producing 35 tons of ingots per heat, have basic linings. The ingots are cast to weigh as nearly as possible 10 tons each. The floor of the melting-house, as shown in *Fig. 1*, is on one level, both behind and in front of the furnaces, with the exception of a small pit in front of each furnace, in which stands a ladle large enough to hold the full charge. The ladle when filled is lifted bodily out of the

[1] Journal of the Iron and Steel Institute, 1887, No. 1, p. 126.

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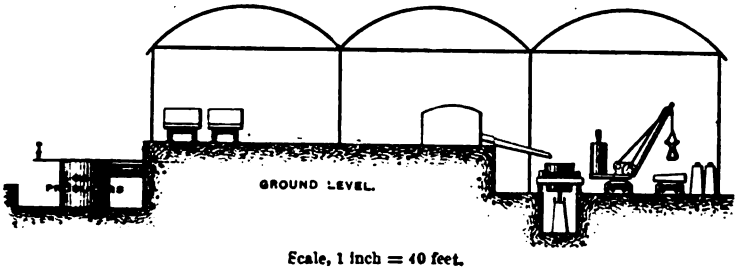
pit by an electric overhead crane, and is brought over a row of ingot-moulds into which the metal is successively poured. Each mould stands on a four-wheeled bogie running on a narrow-gauge railway. When empty the ladle is prepared for the next charge and replaced in the pit. The row of freshly-poured ingots is at once hauled by an endless rope out of the melting-house, and into the stripping-house, which is a separate building. Each bogie in succession is there brought under the "stripper," Fig. 2, Plate 1, consisting of a hydraulic ram of two diameters, moving in a vertical overhead cylinder, and carrying on its upper end a second cylinder having independent motion. Suspended from this cylinder is a pair of links engaging with lugs on the ingot mould. The lower end of the ram is planted on the top of the ingot, while the upper cylinder is caused to rise, carrying the mould with it. As soon as

*Fig. 3.*




Scale, 1 inch = 40 feet.

TYPICAL ENGLISH MELTING-HOUSE.

the ingot is free and no longer needs holding down, the ram ascends, carrying with it the upper cylinder and the mould. The entire stripper is then pushed sideways in V-grooves by a third hydraulic cylinder, and deposits the mould on another bogie on a parallel line of rails, to be returned to the melting-house for refilling. The ingot itself having lost but little heat, is hauled forward to the cogging-house, where it is promptly seized by an electric crane. The brickwork cover having been drawn aside, it is plunged into a vertical soaking furnace to await there its turn at the cogging-mill.

A melting-house such as is usual in steel-plate works in England is shown in cross-section in *Fig. 3*, the ingot-moulds being manipulated by bogie steam-cranes, and never leaving the melting-house. The ingots require separate loading upon bogies by the same or a similar crane. They are then drawn by a small locomotive or otherwise to the vertical heating-furnaces, into

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which they are deposited by radial hydraulic, or bogie cranes. In some cases the bogie crane performs all the operations. The greater heat in summer, and the less need for economising space, in America, have no doubt led to the removal of the moulds from the melting-house immediately after pouring, and to stripping in a separate building. The plan of keeping both ingots and ingot-moulds always on bogies facilitates the work in several ways.

It will thus be seen that much handling of material is avoided in the American as compared with the English system, as is also shown by the following comparison, in which no account is taken of horizontal hauls of lifts, from the time the raw materials arrive at the works until the ingot is stripped ready for the soaking-furnaces.

*English System.*

(1) The raw materials are lifted by an incline or hoist to the level of the charging-platform.
(2) The ingot-mould is stripped and deposited on the ground.
(3) The ingot is lifted and deposited on a bogie.
(4) The ingot-mould is lifted and replaced in the casting-pit.

*American System.*

(1) The ladle of molten steel is lifted for pouring and returned to the casting-pit.
(2) The ingot-mould is stripped and deposited on a bogie.

*Ingot-Soaking Furnaces.*—The Author has described the course of a 10-ton ingot as far as the vertical soaking-furnace. The additional heat here required is produced in the Pittsburg works by natural gas, the air alone being heated by the regenerators. Soaking-pits without extraneous heating, as introduced by Mr. John Gjers,[1] do not seem to be in use in the United States, and indeed they are but little used in Great Britain. It should however be mentioned that Mr. James Riley, of Glasgow, working with large ingots, adopted, some time ago, eight such pits, in combination with four fired by gas, and operated them without difficulty, notwithstanding the loss of heat at week-ends. On Monday mornings the first round of ingots was placed in the non-fired pits which they heated to the proper working temperature, and they were

[1] Journal of the Iron and Steel Institute, 1882, No. 1, p. 565.

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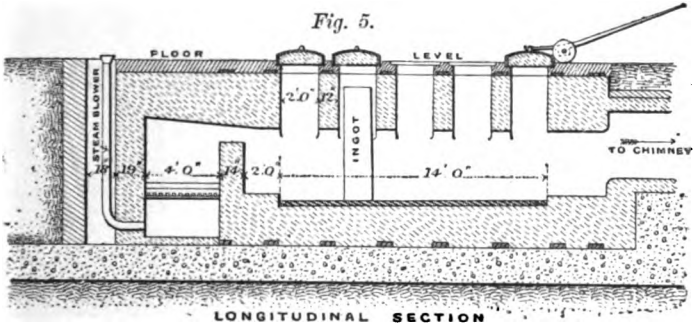
then passed through the gas-fired pits before being rolled. For the rest of the week no external heat was applied, the molten interior of the ingots supplying quite sufficient when evenly distributed throughout the mass. The weight of these ingots was between 5 tons and 7 tons each. Mr. Riley considers that heavy ingots, in which the store of heat is large compared with the radiating surface, can easily be worked as described; whilst for lighter ingots, extraneous heat must always be added.

In Fig. 4, Plate 7, is shown a vertical soaking-furnace heated by producer-gas, as used in America in districts where natural gas is not available, with covers on wheels which are drawn aside by hydraulic cylinders; and in *Figs. 5* and *5a* is shown a vertical ingot soaking-furnace fired by coal, as frequently used in England. In this furnace the door is lifted by a steam or hydraulic radial

*Fig. 5.*




Scale, 1 inch = 10 feet.

ENGLISH VERTICAL INGOT-HEATING FURNACE (COAL-FIRED).

crane, or by a long lever on wheels called a "janger." Either of these methods involves more labour than the American plan, which is usually operated by the furnace-man. From the soaking-furnace the ingot, when sufficiently heated, is lifted by the overhead electric crane, and placed in a tippler from which it is tipped upon the end of the cogging-mill live rollers, when cogging proceeds. The cogging-mill contains one stand of two-high steel rolls with live-roller frames at the back and front; it is supplied with tilting gear, and is driven by a pair of geared reversing-engines. It does not materially differ from English practice, and therefore need not be further described. At one of the newest steel-rail works in the United States, the reversing-engine, driving a large cogging-mill, is coupled direct to the train without the intervention of any diminishing gearing. This appears to be a new feature, indicating an increasing tendency

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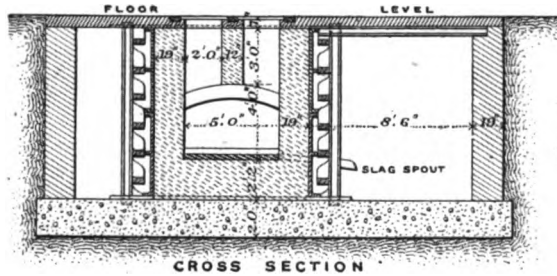
towards direct working. The engine in question has two cylinders 55 inches in diameter with a stroke of 60 inches.

*Hot-Bloom Shears.*—American hot-bloom shears are usually of the hydraulic type, the cut being effected by forcing upwards the lower blade. In this way the necessity of having one of the roller-frames pivoted, which is essential when the cut is downwards, is obviated. In England the usual practice is to cut with a triple-geared, double-cylinder engine of sufficient power without a fly-wheel.

*Direct Rolling.*—The Author proposes now to describe an American works in which ingots of various sizes are cast from open-hearth furnaces, and after being re-heated (or soaked), are supplied direct to the plate-mill, without passing through the preliminary process of cogging. As before explained, the open-

*Fig. 5a.*




Scale, 1 inch = 10 feet.

ENGLISH VERTICAL INGOT-HEATING FURNACE (COAL-FIRED).

hearth furnaces are either acid- or basic-lined, according to the steel-making materials available, and to the purpose for which the plates are intended. When the ingot is to be rolled direct into a plate, ascensional or bottom casting is always resorted to. To save space and time the ingots are not cast separately, but in groups of six as shown in *Figs. 6*. There is one central runner, from which the metal is led through radial ducts of fire-brick embedded in a cast-iron base-plate into the bottom of each mould. The top end of the ingot is usually more even and freer from sponginess and side-splashing than if cast from above; but it is never quite equal in shapeliness to a cogged and sheared bloom. It will be observed that only one re-heating is necessary where ingots are rolled direct, as compared with two where cogging is resorted to, and for this natural or producer gas may be used in a vertical furnace, similar to that already described.

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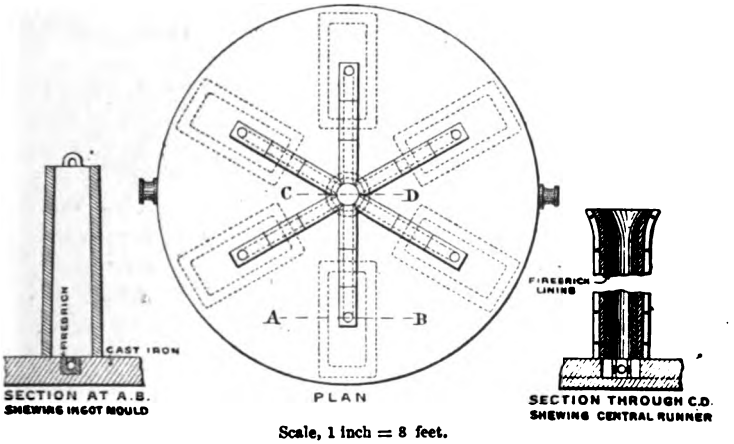
Between one and five ingots may be placed in each pit. The charging and drawing are effected by an overhead electric crane. The surface of the plates made direct from ingots seems to be as good as in the case of those made from blooms; and both makers and consumers agree that rejection, either on that account or on account of failure of tests, are now very rare. The tests to which ship- and boiler-plates are subjected in the United States are similar to those required in Great Britain. Particulars of these tests are given in the Appendix.

*Plate-Mills.*—Whether supplied with ingots or cogged blooms one type of plate-mill (for plates of ordinary dimensions) is in universal use in the United States; whereas in Great Britain another type materially differing from it is almost exclusively

*Figs. 6.*




Scale, 1 inch = 8 feet.

CAST-IRON PLATE FOR BOTTOM-CASTING.

employed. The American standard plate-mill, of which an example is shown in Figs. 7, Plate 7, is driven by a non-reversing non-condensing single-cylinder horizontal engine, working with steam at 90 lbs. per square inch, and furnished with automatic cut-off gear. It has a fly-wheel weighing 50 tons and cylinder measuring 54 inches by 72 inches. This engine turns the central helical pinion of a stand of three rolls. The diameters of the upper and lower rolls are equal, but larger than that of the central one in the ratio of 3 to 2. The upper and lower pinions are coupled to the upper and lower plate rolls, which are each 34 inches diameter and 124 inches long. The middle roll is 24 inches diameter and is driven only by frictional contact with the top or

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bottom rolls. The three rolls are of chilled cast-iron, and are kept cool by water flowing continuously upon them. It will be noticed that although the crank-shaft of the engine is coupled direct to the train, or to the middle pinion, the effect of diminishing gearing is obtained by the above arrangement of pinions, and any further gearing is dispensed with. Before and behind the rolls are pivoted live-roller tables, which are lifted and lowered simultaneously by a hydraulic cylinder, through a system of counterweighted bell-cranks. The middle roll is at the same time lowered or raised by hydraulic power to admit the piece through the upper or lower opening. The screwing-down gear is often worked by an electric motor. An ingot such as is usually rolled to a plate in this mill measures 48 inches by 36 inches by 12 inches, and weighs about 2½ tons. There are no roughing-rolls, the reduction from the ingot to the finished plate being performed in this stand of three chilled rolls, and therefore no side transfer-gear is needed.

A standard English plate-mill is shown in Figs. 8, Plate 7. It consists of two stands of two-high rolls, each 30 inches in diameter by 96 inches long; one pair being grain or unchilled rolls for roughing, and the other pair chilled for finishing. The two pairs of rolls, used in succession for each plate rolled, involve two fixed live-roller tables on one side of the rolls, and one traversing live-roller table on the other side. The screwing-down gear is actuated by a small steam-engine. The mill is driven by a pair of non-condensing, reversing engines, having cylinders 42 inches in diameter, by 60 inches stroke, and geared in the ratio of 2¼ to 1. The second-motion shaft is coupled direct to the lower of two equal helical pinions, which drive the top and bottom rolls respectively.

*Speed-Reduction.*—It will be noticed that in the English practice the two functions of speed-reduction and distribution of power to the top and bottom rolls are performed by two separate sets of toothed wheels, or four wheels in all. In American practice the same functions are performed by one set of three pinions. Assuming the same average pressure on the pistons, and the same number of revolutions per minute, it will be found that the single engine which drives the American standard plate-mill exerts about double the indicated horse-power developed by the pair driving the English standard plate-mill. Taking into account the ratios of gearing and diameters of the rolls, it will be further found that the total thrust at the surface of the rolls is about the same in either case, and that the extra power of the American engine is expended in producing higher speed. Where plates are

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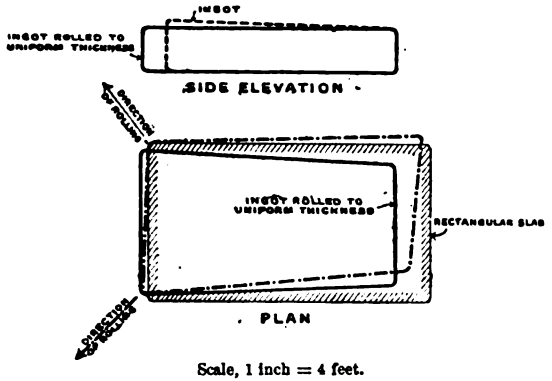
rolled from ingots without intermediate reheating, speed is evidently of great consequence, to avoid undue cooling. Where they are made from cogged blooms, which are much thinner at the commencement, the high speed of the American mill results in large outputs, as shown in the Table at page 149.

*Re-heating Blooms.*—The English plate-mill deals with blooms which have been cogged, hot-sheared, and re-heated in a heating-furnace, which may be either horizontal or vertical. In the latter case the blooms are usually brought from the bloom-shears by a bogie steam-crane, and placed two deep, with fire-bricks between, into one of the heating-furnace chambers; and when ready are lifted out separately by a similar crane, and placed for rolling on the live-rollers of the roughing-rolls.

*Figs. 9.*




Scale, 1 inch = 4 feet.

METHOD OF ROLLING A TAPERED INGOT TO A RECTANGULAR SLAB.

*Rolling Tapered Ingots.*—When a plate-mill deals with cogged blooms which are rectangular in every direction, rolling into a plate of uniform breadth and thickness is an easier operation than when, as in America, flat ingots, tapered say to the extent of an inch in both breadth and thickness, are used. The taper is necessary to enable the ingot mould to be stripped, and must afterwards be eliminated by manipulation during rolling. In American practice the ingot first enters the rolls flatwise, with the thin end leading. The effect of rolling is always to elongate in the direction of motion, to an extent proportional to the reduction in thickness; the breadth is not affected. The tapered ingot is thus reduced to one of uniform thickness, with increased length, but still tapered in breadth, as shown in *Figs. 9.* This side taper cannot be removed by rolling the ingot edge-

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wise, as in a cogging-mill, because the top roll cannot be sufficiently raised to admit it. It is therefore passed through the rolls with the broad end first, and cornerwise, allowing first one corner and then the other to lead. In this way the narrow end is spread out sideways to right and left, and a rectangular slab is the result. On the return passes the narrow end must be made to enter the rolls square. The manipulation is managed by the roller and his assistant, who operate with bars and suspended levers.

*Cooling and Shearing.*—In English iron-plate mills, a few of which still exist, each plate when rolled is received on a two-wheeled flat-topped hand-bogie, and deposited in a vacant place on the iron-plated floor of the mill. There it is flattened by wooden mallets, and by running the bogie over it. Then it is stamped, and, when sufficiently cool, is turned over for inspection of the under side, and marked for shearing according to specification. It is then lifted at one end by the forkers (or shearman's assistants), whilst a bogie is pushed beneath it, and it is wheeled to the shears and placed on the table (or "horse") in front. A portion of the weight of the plate is carried during the process of shearing by the forkers, each of whom holds the edge between the prongs of a fork. When finished it is again placed on the bogie and deposited in the railway-wagons or in a pile for loading as soon as it is passed by the inspector.

In modern English steel-plate mills this somewhat laborious process of handling has been altered. The live rollers on the delivery side are fixed with their upper surfaces nearly level with the floor, and consequently the finished plate can be delivered thereon without the intervention of the hand-bogie. This is an improvement of considerable importance, as the hand-bogie, carrying part and trailing the remainder of a long red-hot plate, is very apt to cause an amount of buckling which cannot easily be eradicated. A pair of gripping-tongs, connected with a chain and steam-winch, is now fixed to the plate, and by means of movable snatch-blocks it can be hauled to any part of the floor which may be vacant, and there left to cool. The marking, lifting, and shearing are, however, still carried out as described above.

The points in the English method of dealing with plates, after leaving the finishing rolls, which are open to objection, are as follows:—

(1) The plates are cooled on a floor, which necessitates subsequent lifting by hand, an awkward operation at the best.

(2) As the floor soon becomes hot, and as the top side only of the

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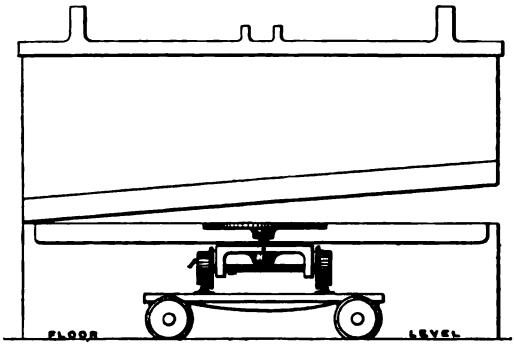
deposited plates can be relied on to give off heat, the time of cooling is unduly prolonged.

(3) As a considerable portion of the weight of the plate must be supported by the men during shearing, a large gang of exceptionally strong men (about twelve in all) is required for the work.

To diminish the strain on the forkers, a truck, *Fig. 10*, was devised some years ago at one of the northern plate works, where, the Author believes, it is still in operation. It has four wheels running on a pair of rails level with the floor, and parallel with the shear-blades. The truck-frame carries a pair of rails at right angles with the shear-blades, and on these runs a secondary truck with turn-table top and screw adjustment for height. By the use of this truck instead of the ordinary fixed

*Fig. 10.*




Scale, 1 inch = 4 feet.

UNIVERSAL TRUCK FOR PLATE-SHEARS.

table, the men are able to quickly move heavy plates horizontally in any direction, without themselves carrying any considerable portion of the weight. Nevertheless, the firm has not been able to reduce the number of its forkers nor its piece-work rates, though probably it is less dependent on a few picked men. This may to some extent account for the device not having been generally adopted.

As regards plate-shearing American practice differs considerably from English, and in some ways it seems superior to it. Thus, in the United States, when a plate is finished as far as rolling is concerned, it is carried forward by the live rollers, on the delivery side of the plate-mill, to a further series of live rollers placed in continuation of them. This extends, in some instances, for no less a distance than 360 feet from the centre of the plate-mill, and terminates at



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the shears. The finished plate, arriving red-hot on the first rollers of this series, remains there cooling on both the upper and lower surfaces, until the next plate is finished, when it is moved forward a stage to make room for the latter. There it remains, still cooling, until another plate is finished, when it is moved on a further stage. In current work the entire series of rollers is covered with plates from end to end. If the plates be 20 feet long on the average, and require three minutes each for rolling, then eighteen stages of three minutes, or fifty-four minutes in all, would be necessary for a plate to traverse the whole length of the series, and that time is sufficient to reduce them to a temperature which admits of their being examined and marked off before arriving at the shears. It might naturally be supposed that plates which, whilst still red-hot, are supported only by rollers, would become buckled. That, however, does not appear to be the case, at least with such as are $\frac{1}{4}$ inch thick and upwards. When cool they are nearly as flat as if they had been laid on an iron floor as in the English method. Should they show any tendency to buckle owing to being finished very hot, they are moved by the live rollers backwards and forwards until they are sufficiently cool to remain level.

Instead of having to send his men with a bogie to lift the plates from the floor one by one, whilst he and the shears are idle, the shearman in America stands with his gang of eight men only, including himself, in front of the shears. His first sight of a plate is when it appears between the blades of the machine, marked for shearing. The live rollers run it through, and when the scrap has been removed from the after end, the plate is turned until each of the other three edges have successively been sheared. In this operation the shearman is assisted by a novel appliance which has as yet been adopted only in one instance in Great Britain. The floor-plates in front of the shears and for some distance around it are perforated with holes about $2\frac{1}{2}$ inches in diameter and 18 inches apart. In each of these holes is fixed an upright stanchion with a castor-roller at the top called a "goose-neck," *Fig. 11*, resembling to some extent an ordinary dinner-table leg inverted. The castor-rollers are level with the lower shear-blade. The plate, as it comes through, is at once received on these goose-necks, which carry its weight, and at the same time allow it to be moved about horizontally in any direction without serious effort on the part of the men, who hold it with their hands protected by leathers. When sheared it is pushed forward, still on the castors, to be weighed, lettered and inspected.

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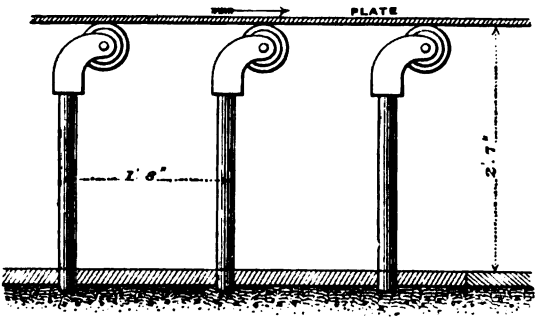
Finally, an electric crane, which spans the whole building, seizes and places it in the truck for shipment, or elsewhere, as may be required. From the ingot to its final resting-place in the truck it is always upon the wheels or rollers, except when it is being re-heated.

Electro-magnets have been used in the United States for lifting plates as shown in *Figs. 12.* They were suspended from an overhead electric crane and electrically connected therewith. The two poles were brought into contact with the plate to be lifted and the current applied. It was found, however, that, if the plate to be lifted happened to lie upon others, some of the latter were apt to adhere to it. Further, when the plate was lowered to the ground and the current cut off, it was not immediately released, a result due to residual magnetism. These

*Fig. 11.*




Scale, 1 inch = 4 feet.

"GOOSE-NECKS" FOR PLATE-SHEARS.

disadvantages and the risk of accidents involved by them have largely led to the discontinuance of the use of electro-magnets for this purpose, even though it was found possible to carry loads of 50 tons by their aid.

*Waste in Plate-rolling.*—In the manufacture of iron plates from piles made of puddled bar and scrap-iron, a pile weighing 35 cwt. is required to make a finished plate of rectangular shape weighing 20 cwt., which is equivalent to a yield of 57 per cent. But as about 5 per cent. of the iron plates made are found to be defective before leaving the works, and have to be cut into scrap, the proportion should rather be 35 cwt. to 20 cwt. — 1 cwt. = 19 cwt., which is equivalent to a yield of 54·3 per cent. The maximum weekly output of the largest iron-plate mill with which the Author is acquainted is about 820 tons.



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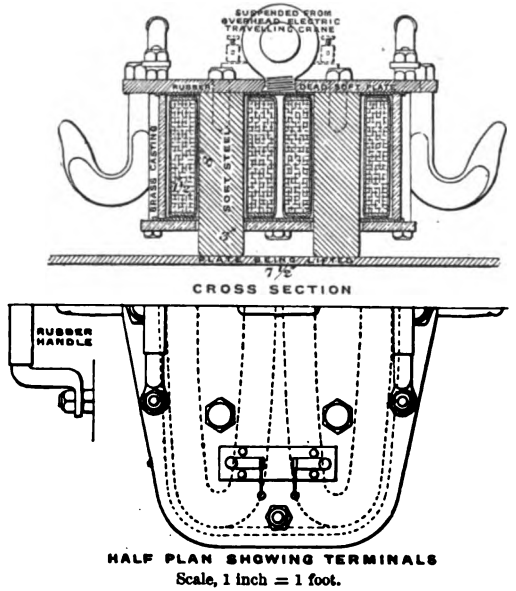
In the manufacture of steel plates, the proportion of unmarketable plates is now exceedingly small on both sides of the Atlantic. There is also less waste than in the case of iron, because (1) A steel ingot exposes less surface to the flames during re-heating than a pile of the same weight. (2) Larger masses are dealt with, which involves less surface in proportion to weight. (3) It is not necessary to obtain a welding heat. (4) Less allowance for shearing is needed. A somewhat greater margin must be allowed where ingots are to be worked in the plate-mill than when cogged and sheared blooms are supplied; but this advantage is partly

*Figs. 12.*




ELECTRO-MAGNET FOR LIFTING PLATES.

compensated by the one re-heating in the place of two, with proportionately less furnace waste.

The Table on the following page shows yields from ingot to saleable plate in typical mills which have come under the Author's notice.

The following deductions seemed to be justified, viz.:—

(1) A plate-mill worked with a cogging-plant will produce (other things being equal) about double the quantity obtainable from a plate-mill alone, worked direct with ingots.

(2) The loss from re-heating is greater in the former case because of the two heatings instead of one.

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(3) But owing to the less margin for scrap, which is necessary when blooms are used in the plate-mill instead of ingots, the former is the more economical of the two methods.

| Letter Indicating Mills. | Ingots or Cogged Blooms. | Maximum Weekly Output. | Saleable Plates Per Cent. of Ingots. | Number of Re-heats. | Re-heating Agent. | Total Furnace Waste of Ingots. | England or America. |
|---|---|---|---|---|---|---|---|
| | | | *Steel Plates.* | | | | |
| | | Tons. | | | | | |
| (*d*) | Cogged | 1,440 | 71 | 2 | Coal | 5 | England |
| (*e*) | „ | 900 | 65¾ | 2 | „ | 5·65 | „ |
| (*f*) | „ | 1,120 | 75¼ | 2 | Producer gas | 3·12 | „ |
| (*g*) | „ | 1,867 | 68 | 2 | Natural gas | 3·5 | U.S.A. |
| | | | Average 70 00 | | | | |
| (*h*) | Ingots | 850 | 66 | 1 | Natural gas | 3 | „ |
| (*k*) | „ | 526 | 69¼ | 1 | Producer gas | 3 | „ |
| | | | Average 67·62 | | | | |
| | | | *Iron Plates.* | | | | |
| (*l*) | Iron piles composed of puddled bars and scrap. | 820 | 54·3 | 2 | Coal | 16·25 | England |

The following figures may be taken as representing fair average results:—One hundred tons of steel in the condition of ingots will yield 69 tons of saleable plates and 26 tons of scrap, whilst 5 tons are lost in re-heating. One hundred tons of iron in the condition of piles will yield about 54 tons of saleable plates and 30 tons of scrap, whilst 16 tons are lost in re-heating.

*Fuel used in Re-heating.*—The quantity of fuel needed for soaking ingots depends (1) on the quantity of heat contained in them when they arrive at the furnace; (2) on the tonnage passed through the latter in a given time; (3) on the method of heating; and (4) on the calorific value of the fuel employed. It varies between almost none at all, as exemplified by Mr. Riley's practice and, say, 2 cwt. per ton where the circumstances are not very favourable. The quantity of fuel needed for re-heating cogged blooms is dependent on similar conditions. It may be taken to vary between 2 cwt. and 4 cwt. per ton of blooms heated. In the manufacture of iron plates from piles in ordinary mill-furnaces, 5 cwt. of good coal is required for the first heating (from cold), and 1½ cwt. for the second heating, making a total of 6½ cwt. per ton of piles heated. Assuming two re-heatings in either case, the total amount of fuel

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would average for steel about 6 cwt., and for iron about 12 cwt. per ton of finished plates.

*Expansion of Rolls.*—So long as plates were made of iron the great widths now obtained in some steel-plate mills were not attempted. In iron-plate mills it usually devolves on the chief roller to turn his rolls and keep them in proper form and condition. This custom still prevails in many steel works in Great Britain. It is not so simple a duty as may appear at first sight. The object aimed at is that the thickness of a plate should be uniform throughout, whatever its width. If the rolls (say in a two-high mill) are turned truly cylindrical, and are worked dry and allowed to become hot, and plates of various widths are, as is usually the case, passed through, the middle portion of the rolls gradually becomes hotter than the ends, and the consequent expansion produces there a greater circumferential velocity. This tends to elongate the central portion of a broad plate more than the sides, and a central ribbon-like buckling is the result. To avoid this trouble, it is customary in England for a roller to turn his rolls slightly smaller in the middle than at the ends. At the beginning of each week he rolls only strips, too narrow to be themselves affected by the tendency to buckle, whilst they serve to heat and expand the middle portion of the rolls. When the latter have sufficiently expanded and become parallel throughout, he is able to roll wide plates without fear of central buckling. In America the difficulties arising from roll expansion are overcome by turning them equal in diameter throughout their length, and keeping a plentiful supply of cooling water running over them. This seems to answer perfectly for all plates except those less than ¼ inch thick, which are relegated to a separate mill where the rolls are short in proportion to their diameter, and are worked hot and dry. The water falling on the plates in the larger mill does not cool them as much as might be expected. It always assumes the spheroidal condition, and rolls off without sensible evaporation or absorption of heat, carrying with it any loose scale which may have formed.

In such extreme widths as are now occasionally demanded and made, such as say 13 feet, fresh difficulties arise from the springing apart of the rolls in the middle. If they were turned of slightly larger diameter there than at the ends, the springing would be compensated for, and a plate of even thickness would be produced. This is, however, inadmissible, since it would involve differential velocities, and buckling would result as before described. A plate 13 feet wide, if rolled to a thickness of say ⅝ inch at the edges, would

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certainly be $\frac{1}{16}$ inch thicker in the middle. This spring in the rolls can only be minimized by having them as large in diameter as possible and taking such means as have been described to keep them uniformly cool.

*Scrap.*—It is obvious that in any works designed for the manufacture of steel plates, the financial results must depend largely on the yield or weight of saleable plates obtained from a given weight of ingots. To reduce the proportion of scrap without running the risk of imperfect edges, is always a principal duty of the plate-mill manager. As the scrap allowance is in the form of a certain margin all round the plate, it is clear that some forms involve more scrap than others. A plate of large area in proportion to the length of its sides, such, for instance, as one square in shape, involves less scrap than one in which the area is small compared with the length of its sides, such as a long narrow strip. The yield of a plate-mill depends, therefore, much on the specifications on which it has to work. The best yield is obtained where a steady flow of large square or oblong plates can be secured, and the worst where long strips are mainly needed. The total output of the mill is similarly affected to some extent. But outputs are still more affected by the average weight of the ingots or slabs rolled. It is manifest that an ingot or slab weighing 1 ton, and rolled into a thick plate, would not necessarily occupy the mill longer than one weighing $\frac{1}{2}$ ton and rolled into a thinner plate. Yet the output reckoned by weight in the former case would be double that in the latter. This points to the advantage of laying out plate-making works in such a way that orders may be sorted, and each size or shape made in a mill adapted to it. Where a works contains one mill only, it must often be employed wastefully on sizes and thicknesses unsuited to it.

*Supplementary Mills.*—The American standard plate-mill is most advantageously used in conjunction with a universal or "Belgian" mill. This mill is able to roll strips up to 100 feet long, and down to $\frac{1}{2}$ inch thick by 3 feet broad, or $\frac{1}{4}$ inch thick by 1 foot broad, and its total output has reached 900 tons per week. It has two horizontal plain chilled rolls, and two pairs of similar rolls of smaller diameter arranged vertically, one pair being at the front and the other at the back of the horizontal rolls. The universal mill is driven by a pair of horizontal geared reversing engines with 30-inch cylinders. The screw-down gear of the upper horizontal roll is actuated by a hydraulic cylinder with intervening rack and pinions. The vertical rolls are driven by spur- and mitre-gearing from the train pinions, and are adjusted

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horizontally by hand-gear. This mill is fed with ingots from two ordinary horizontal heating-furnaces specially allotted to it. The ingots are drawn out by hydraulic rams and delivered to the live rollers on the entering side by hydraulic swing-cranes. The live rollers on the delivery side pass the finished strip, which requires no side shearing, into a straightening press where it can be straightened horizontally. It is then sheared at both ends to the required lengths, and is ready for loading up.

The main mill is usually further supplemented by a sheet-mill of ordinary construction, and supplied with small ingots from two heating-furnaces similar to those last described. In this mill sheets 5 feet wide and between $\frac{1}{4}$ inch and $\frac{1}{16}$ inch thick, and smaller widths down to No. 24 gauge, can be produced; thus relieving the standard mill of all work below $\frac{1}{4}$ inch thick. A similar sheet-mill is often used as an adjunct to English plate-mills, and, indeed, in this respect, there is no difference in practice in the two countries. The American plate-mill, relieved of narrow and thin work, is in a much better position for making large outputs than would otherwise be the case. As before stated, it usually has rolls 34 inches in diameter by 124 inches long, and therefore cannot roll plates more than 9 feet 6 inches wide; but, as has been shown, it deals with plates of all smaller widths down to 3 feet, and all thicknesses down to $\frac{1}{4}$ inch. The standard English plate-mill, having rolls 30 inches in diameter by 96 inches long, cannot roll plates more than 7 feet 8 inches wide; and as universal mills are but little used in England it deals with all smaller widths and thicknesses down to $\frac{1}{4}$ inch.

The English practice is, in fact, to use a smaller mill for general work than is the custom in America. But this smaller mill has, of late years, been usually supplemented by a very large one, Figs. 15, Plate 7. This has but one stand of chilled rolls 162 inches by 40 inches, and is driven by a pair of reversing engines with cylinders 48 inches in diameter by 60 inches stroke, geared in the ratio of 3 to 1. Plates 13 feet wide can here be rolled. Such plates are occasionally required for marine boilers, but their proportion to the rest is very small. Whether the American 124-inch mill, supplemented by a universal mill and a sheet-mill, or the English 84-inch mill, supplemented by a 162-inch mill and a sheet-mill, is most likely to compass the usual market demands with greatest economy, is a difficult question to answer. The two systems, which manifest a considerable difference of opinion and of practice, are possibly reflections of the different requirements of the market on the two sides of the Atlantic.

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*Plate-Shears.*—In Figs. 13, Plate 7, is shown a modern plate-shears as used in England. It will shear a plate 2 inches thick, will pass one 13 feet wide between the frames, and, having 37-inch gaps, will split one 6 feet wide and of unlimited length down the middle. It is driven by a pair of reversing engines of such power that, aided by triple gearing, the maximum cut can be commenced or recommenced and continued without a fly-wheel. It will be noticed that the whole stress of the cut is taken by strong bolts, the intervening castings being made in sections and acting merely as distance pieces. In the United States the largest plate-shears seen by the Author are not adapted to pass plates of greater width than 11 feet between the frames. They can, however, shear up to a thickness of 2 inches. The shears are there usually driven by a single cylinder aided by a fly-wheel, as was formerly the practice in this country.

In Figs. 14 and 15, Plate 7, are shown a typical American steel-plate works laid out as described, and an English works, each capable of a total average output of, say, 1,500 tons per week.

*Summary of Conclusions.*—The Author is of opinion that the following conclusions may be drawn from this comparison between American and English methods of manufacturing steel plates, viz.:—

(1) There being no extensive demand for ship and marine boiler-plates in America such as obtains in Great Britain, several other important uses have been developed.

(2) American practice supports the view that equally good steel may be made by any of the four modern processes if equal care be taken; and that basic linings to open-hearth furnaces are advantageous, even where high-class pig-iron is plentiful.

(3) It also shows that, as regards the quality of product and economy of production, the intermediate process of cogging is by no means indispensable.

(4) By the extensive adoption of labour-saving appliances (more especially electric motors), and by keeping the work in progress almost continually on wheels or power-driven rollers, labour is minimized in America to an extent seldom reached in Great Britain.

(5) The American standard plate-mill is, in the Author's opinion, superior to that usual in this country, because it admits of a quicker reduction in the thickness of the ingots or blooms submitted to it, a more economical engine, and less intermediate gearing. The single stand of three chilled rolls, worked always

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wet, is simpler and better than two stands of rolls, with one traversing and two fixed roller-frames.

(6) The American plan of cooling the plates on live rollers, and inspecting and marking them in transit, appears to be a decided improvement on English practice, and so also does the use of castor-rollers in front of the shears.

(7) The best performance in the United States does not differ greatly from the best performance in this country, as shown in the Table at p. 149. Steel in both cases compares very favourably with iron-plate making.

(8) The modern English plate-shears, actuated by a pair of cylinders without a fly-wheel, is an improvement on the existing American practice.

There are many other points in which English practice still takes the lead. But the Author refrains from referring to them at greater length, his object being rather to direct the attention of English engineers to American improvements. In conclusion, he desires to record his thanks to various gentlemen who have assisted him with information, especially Messrs. McIntosh, Hemphill & Co., of Pittsburg, Mr. A. Lamberton, of Coatbridge, Mr. H. W. Hollis, of Spennymoor, Mr. John Hill, of Middlesbrough, Mr. George Bartol, of Cleveland, Ohio, and his son, Mr. Archibald P. Head, who has throughout given him valuable aid in preparing the communication.

This Paper is accompanied by nineteen drawings, from which Plate 7 and the *Figs.* in the text have been prepared.

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APPENDIX.—CHEMICAL AND PHYSICAL TESTS REQUIRED BY CERTAIN USERS OF STEEL PLATES IN GREAT BRITAIN AND AMERICA.

| Country . . | Great Britain. | | | | | | | United States. | | | | | | | | | | | | | | Canada. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifying Authority. | Lloyd's Registry. | | Board of Trade. | | Admiralty. | | | United States Navy. | | | | Pennsylvania Railroad Company. | | Baldwin Locomotive Company. | | Brooks Locomotive Company. | | U.S. Revenue Department. | American Boiler-Manufrs. Assoc. | Canadian Pacific Railway Company. | | |
| Uses for Plates . | Ship. | Boiler. | Boiler-Shells. | Boiler Fire-boxes. | Ship. | Boiler-Shells. | Boiler Fire-boxes. | Ship. | Boiler. | Nickel-Steel Armour Plates. | Steel Castings. | Locomotive-Shells. | Locomotive Fire-boxes. | Locomotive-Shells. | Locomotive Fire-boxes. | Locomotive-Shells. | Locomotive Fire-boxes. | Ship. | Boiler. | Locomotive Fire-boxes. | | |
| *Mechanical Tests.* | | | | | | | | | | | | | | | | | | | | | | |
| Ultimate tensile strength, tons (2,240 lbs.) per square inch, limits . . . | 28 to 32 | 26 to 30 | 27 to 32 | 26 to 30 | 26 to 30 | 26 to 30 | 24 to 26 | not under 27 | 26 to 30 | not under 36 | not under 27 | 25 to 29 | 25 to 29 | 25 to 29 | 25 to 29 | 25 to 29 | 25 to 29 | not under 25 | 25 to 28 | 22 to 26 | | |
| Elongation per cent. in 8 inches . . . | 20 | 20 | 20 in 10 inches. | 20 in 10 inches. | 20 | 20 | 26 | 25 | 25 | 22 | 10 to 15 | 26 | 28 | 25 | 25 | 20 | 28 | 25 | 25 | 28 | | |
| *Chemical Tests.* | | | | | | | | | | | | | | | | | | | | | | |
| Carbon, not to exceed. . . | No chemical tests. | | | | | | | .. | .. | .. | .. | 0·25 | 0·250 | 0·25 | 0·250 | .. | 0·250 | .. | .. | .. | | |
| Phosphorus, do. . | | | | | | | | 0·06 | 0·035 | 0·035 | 0·1 | 0·05 | 0·035 | 0·05 | 0·030 | .. | 0·035 | .. | 0·04 | 0·025 | | |
| Manganese, do. . | | | | | | | | .. | .. | .. | .. | 0·45 | 0·450 | 0·45 | 0·450 | .. | 0·450 | .. | .. | 0·400 | | |
| Silicon, do. . . | | | | | | | | .. | .. | .. | .. | 0·05 | 0·030 | 0·03 | 0·030 | .. | 0·030 | .. | .. | 0·025 | | |
| Sulphur, do. . | | | | | | | | 0·04 | 0·04 | 0·04 | .. | 0·05 | 0·045 | 0·05 | 0·035 | .. | 0·035 | .. | 0·03 | 0·025 | | |
| Nickel, do. . . | | | | | | | | .. | .. | 3·00 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | | |

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(*Paper No. 2904.*)

# "Four American Rolling-Mills."[1]

By SAMUEL T. WELLMAN.

THE development of labour-saving appliances in connection with American rolling-mills, may be said to have commenced when Mr. George Fritz built the first blooming-mill at the Cambria Iron Works in July, 1871. Mr. A. L. Holley had already built, in January, 1871, a blooming-mill at Troy, but it had no manipulator or apparatus for turning the ingot, and the rollers in the lifting-tables were not driven by power, both these operations being performed by hand, with hooks and tongs. The Holley blooming-mill was three-high, with fixed top and bottom, but movable middle roll, which was adjusted at every pass to give the required draught. In the Fritz mill the middle roll was fixed, the top and bottom rolls being adjusted to it at each pass. The table rollers were geared together and were driven by V friction-rolls, which were belted from the mill itself. The rollers could be driven in only one direction when the table was up and in the opposite direction when the table was down. This method of driving the rollers was not very satisfactory, and was afterwards replaced by a small double-reversing engine, by which they could be driven in either direction in any position of the table. This was first proposed and adopted by Mr. John Fritz at Bethlehem, the power being transmitted through a belt, which was improved on by Mr. Holley, who used gearing instead of belting. This method of driving the table rollers has withstood the test of many years' hard work, no change having been made until within the last two years, when the electric motor has, in some new mills, taken the place of the small engine. The electric motor will, the Author considers, replace the small steam-engine in iron and steel works.

The manipulator for turning over and adjusting the ingots from one groove to another was the invention of Mr. George Fritz. It is very simple and effective, and has proved well adapted to the work remaining to-day exactly as the inventor left it. The adjustable rolls in three-high blooming-mills have been discarded, and all

[1] The discussion upon this communication was taken in conjunction with that upon the preceding one by Mr. Jeremiah Head on "Manufacturing Steel Plates."

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modern American three-high blooming-mills have fixed rolls, one pass at the top and bottom being generally made in each groove. Most American Bessemer-steel works, where rails are made, use exclusively or largely the three-high blooming-mill; but some, notably the Cambria Iron Works, the home of the three-high mill, have adopted the reversing-mill.

The two works which hold the record for greatest output are the Edgar Thomson and the South Chicago, both having three-high blooming-mills. There seems to be no question as to the superiority of the three-high blooming-mill for producing a great quantity of blooms of one size. On the other hand, if a mill has to make all sizes of blooms and slabs, the two-high reversing mill is undoubtedly preferable, as all sizes of squares and flats within the range for which the mill is adapted can be made on one set of rolls. As the tendency is more and more for every works to make all sizes and shapes, it seems likely that the reversing mill for roughing down steel ingots to blooms or slabs will largely take the place of the three-high mill.

For finishing rails and other heavy bars, the three-high, or Fritz, mill is almost universally used in the United States, the most notable exceptions being the rail-mill at the South Works of the Lackawanna Iron and Steel Company at Scranton, Pa., and the new mills of the Johnson Company at Loraine, Ohio, in course of construction. The Scranton Works have produced excellent work, but the tonnage has not reached that turned out at some of the other works. In this Paper the Author proposes to deal more particularly with the machinery and appliances to save labour and time in handling the piece round the rolls, which have been introduced and brought to a high degree of perfection within the past ten or eleven years. The first improvement in this direction was made by Mr. Robert W. Hunt, who, in 1884, introduced tables with driven rollers in front of the finishing rolls of the rail train of that company, at Troy, N.Y. They worked well from the commencement, so that tables were soon added to the roughing-rolls. Tables with driven rollers, arranged similarly to those at the Troy Works, were soon added to the rail-mill at the Edgar Thomson Steel Works. These tables worked well from the first; and the saving of labour was very large and at the same time the product was greatly increased. Mr. Hunt has stated the number of men required to operate a three-high rail-mill in the old-fashioned way to be between fifteen and seventeen. The introduction of the tables and appliances referred to, reduced this number to four or five, including the roller, besides rendering possible a great increase in the output of the mill.

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### The Joliet Works of the Illinois Steel Company, Joliet, Illinois.

In 1885 the Joliet Steel Company added automatic machinery to its rail-mill, and in 1894 it remodelled the ingot-heating plant in the blooming-mill, erecting new Siemens regenerative heating-furnaces, and Wellman electro-hydraulic charging-machines. By the courtesy of the Company the Author is able to present a general plan of the rail-mill at the Joliet works as remodelled, and also an outline plan showing the passes and course of the rail through the rolls, Figs. 1 and 2, Plate 8. The charging-machines, Fig. 1, Plate 8, and Figs. 7, Plate 9, are built on a framework of steel I beams, mounted on four wheels, which run on a broad-gauge line in front of the furnaces driven by an electric-motor, geared to one of the axles in the same manner as the electric tram-cars. The ingots are brought in front of the heating-furnaces from the converting works, standing upright on the ingot-wagons. All the movements of gripping, lifting, tipping down, placing in the furnace, turning over in the furnace if necessary, and taking out, are made by hydraulic power. The triple pumps are driven by an electric-motor and are mounted on the machine. The starting and stopping of the pump is automatically effected by the variation of the pressure working the rheostat. The accumulator consists simply of a tank filled at the start with compressed air at about 100 lbs. per square inch pressure, the water being pumped in against the pressure until it reaches about 400 lbs. per square inch. The performance of these machines has been very satisfactory, and the saving of labour greater than has hitherto been attained in dealing with such ingots at the blooming-mill. One heater has charge of the five furnaces, and an assistant is attached to each furnace, and an operator for each machine.

The ingot when taken out of the furnace is placed on a wagon standing on the narrow-gauge line in front of the furnace-door. This wagon is moved by a small steam-engine at one end of the building, through the medium of a wire rope, to the end of the extension of the blooming-mill approach, Fig. 1, Plate 8, which reaches back between the furnaces. The ingot-wagon has geared rollers on which the ingot lies. When it stops in front of the table, an "idler" is forced up from below by power, connecting the wagon with the table. The table-rollers are driven by a small steam-engine. The ingots pass from the extension-table to the blooming-mill table, the rollers in which are also driven by a

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steam-engine. The blooming-mill is a Fritz three-high mill, with the three rollers fixed. The ingot, which measures 16 inches by 16 inches, and is large enough for four rails, is rolled in thirteen passes to 7½ inches by 5½ inches. The bloom is carried over driven rollers to the bloom-shear where the top and bottom end of the bloom is cut off, and the bloom is cut into two pieces, each of which is rolled into two rails. The scrap-bloom ends drop on a conveyor in the pit under the shear, by which they are lifted and dropped into wagons. The blooms then pass from the shears first to the roughing-rolls. The automatic machinery for manipulating the piece at the roughing- and finishing-rolls—designed for the most part by Mr. F. H. Treat—is one of the most ingenious and effective pieces of rolling-mill machinery in existence, and reflects the highest credit on the inventor's mechanical skill and genius.

The bloom passes, Fig. 2, Plate 8, direct from the shears over the live rollers to the first pass in the roughing-mill, through which it is drawn, between the middle and lower rolls, on to the lifting-table. It is here lifted and at the same time carried sideways far enough to bring it opposite the next groove, through which it passes into the turning-trough. This is hinged at the bottom, and as it lowers the piece, gives it a quarter-turn, so that it drops on the live rollers in the proper position to enter the third groove. The operation of lifting the piece from the third to the fourth groove is the same as that from the first to the second. Generally the second bloom is making the first pass while the first is making the third. The lowering and turning over from the fourth to the fifth groove is performed in exactly the same manner as that from the second to the third, and the lifting from the fifth to the sixth in the same way as that from the third to the fourth. As the piece comes through the sixth pass it slides down inclines on to the live rollers in front of the seventh pass in the finishing-rolls, in passing through which to the tilting and vibrating table it is given a quarter-turn by the shape of the rollers. This table is pivoted on the rear end, and as the front end is lifted it is carried sideways until the piece is opposite the eighth groove, through which it passes into the first of the tilting and vibrating troughs. The rear-end of this U-shaped box or trough is fixed and pivoted, and as the front end is lowered it moves diagonally until the piece is opposite the ninth groove. The course through this groove and the tenth and eleventh is the same as before, the finished rail passing from the latter direct to the saws.

A large part of the work at the Joliet Mill during the year

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ending May, 1895, was the manufacture of 4-inch by 4-inch billets of soft steel. In making these special rolls are used in the roughing, the bloom being rolled to 4 inches by 4 inches in five passes. It passes direct from the lifting-table to a small pair of hydraulic shears, Fig. 1, Plate 8, from which the billets pass outside the mill about 1,000 feet by the automatic conveyor. Various sizes of bars and angles have been rolled in this mill, including large quantities of splice-bars for rails and angles as small as 2 inches by 2 inches finished direct from 16-inch ingots without re-heating. When rolling angles or other finished bars, the finishing-rolls are placed in the rail-housings and rolled in the same number of passes as the rails. Generally the first half of the ingot is rolled to the proper size of billet for the required bar, transferred to the finishing rolls and completed; the last half of the ingot at the same time being rolled to 4 inches by 4 inches, and cut in short lengths for the rod-mill. The best twelve hours' work in the mill is 679 tons of billets; the best month's work 27,003 tons; the average work per turn being about 500 tons. The number of men employed at the furnaces and mills is: at the furnaces, nine, including heaters, assistants and charging-machine men; at the blooming-mill and engine, nine; at the rail-train and engines, when working billets, thirteen; and when working rails, seventeen men; the total number of men being thirty-five per turn of twelve hours, or an average of 14·28 tons per man.

In economy of working and uniformity of product, the Joliet Mill stands in the front rank of American rolling-mills—a result reflecting great credit on the former and present managers, Mr. H. S. Smith and Mr. Charles Pettigrew.

### The South Works of the Illinois Steel Company, South Chicago, Illinois.

At the rail-mill of these works, as originally constructed, there was a three-high blooming-mill, but the finishing train was reversing, and was driven by a direct-coupled engine. In 1890 this train was changed to three-high and the interior of the mill was remodelled, nothing being left in its original form except the blooming-mill, and to that a new engine was added. The ground plan of the mill as it now stands is shown in Fig. 3, Plate 8. The heating is performed in vertical gas-furnaces, sometimes miscalled soaking-pits, of the Siemens type, arranged to use either producer-gas or crude petroleum. The ingots are kept in a vertical position from the time they are cast until they pass into the blooming-mill,

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to avoid the possibility of the cavity, due to the shrinkage or piping of the ingot, moving from the top to the side, which would happen if the ingot were laid on its side, while still fluid in the centre. This would cause a dangerous defect in the rail, and one not easily discovered until after the rail is placed in service. There are eight of these furnaces, each holding eight ingots, which are brought from the converting works on narrow-gauge wagons. They are drawn in and out of the furnaces by Wellman hydraulic-cranes, all the motions of which are executed by power.

The heated ingots when ready for rolling are placed on a narrow-gauge wagon running between the furnaces, and driven by a small stationary engine at one end of the line. As it comes in front of the blooming-mill table it is tipped down by a hydraulic cylinder and dropped on the rollers, by which it is carried to the blooming-rolls. These are worked as at the Joliet Mill, the only difference being that the work is done in nine passes instead of eleven. The blooms are generally cut long enough to make three rails each, but sometimes four, each ingot making two blooms, or, in case of very light rails, three blooms. In case the blooms are badly cracked or are too cold to roll direct, or in case of any delay at the mill, the blooms are taken by an overhead transfer to the large heating-furnace, in and out of which they are drawn by a Wellman hydraulic charging-machine.

The rail-trains are 27 inches in diameter. The first, consisting of two stands, carries the first roughing- and finishing-rolls, and is driven by a Porter-Allen engine with a 54-inch cylinder, of 66-inch stroke, running at about 85 revolutions per minute. The second train carries the second and third roughers, and is also driven by a Porter-Allen engine with a 44-inch cylinder, 66-inch stroke, running at about 85 revolutions per minute. The bloom is passed by means of lifting-tables through the first and back through the second pass. As the first lifting-table is lowered the piece is automatically carried over to the third pass. The third and fourth passes are made in the same way as the first and second. As the lifting-table is lowered to make the fifth pass the piece is turned through 90°, and the piece is there carried by the rollers to the stationary table through the sixth pass to a tilting-table. As it leaves this pass it is again turned 90° by guides and by the shape of the grooved rollers in the tilting-table. This table is lifted and the piece passes through the seventh pass, drops on to the stationary table, and again enters the rolls; in the eighth pass it is lifted from the table by the transfer and is carried over to the third set of rolls, in which only one pass is made. From the



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stationary table it is transferred and turned 90° dropping on the live rollers, which carry it to the finishing-rolls, driven from the end of the first roughers. In these rolls the piece receives four passes, the finished rail passing over a stationary table to the saws, from which it is carried through the cambering machine to the hot bed, Fig. 3, Plate 8. The rails are loaded by power from the end of the hot bed on to wagons, from which they are unloaded at the various cold beds in the finishing shop. They are unloaded by an arrangement of levers worked by steam cylinders, the steam being taken from the locomotive and worked by the attendant.

The small demand for rails has forced the South Works to extensively manufacture soft-steel billets. These are finished in the second roughers, being long enough to contain the grooves for 4-inch by 4-inch billets as well as rails. When a soft-steel ingot is to be rolled a switch is thrown in the first stationary table and the piece guided into the proper groove. The piece is given three passes and finished to 4-inch by 4-inch passes over the table to hydraulic shears and by the surface-conveyor to the billet yard, which has a capacity of 25,000 tons. This arrangement for rolling billets without changing rolls, enables the furnaces, blooming-mill and roughing-rolls to be fully employed, while the finishing-rolls for rails are changed for a new section.

The capacity of the mill is very great; as many as 1,025 tons of rails have been rolled in twelve hours, and 1,829 tons in twenty-four hours; during the same month, May 1893, the production of rails reached a total of 38,093 tons.

All the details of this mill were designed under the immediate supervision of the company's engineer, Mr. Robert Forsyth. The capacity of the mill has hitherto only been limited by the ability of the converting works to supply it with ingots. There is no doubt that, if the ingots can be furnished, 50,000 tons could pass through the mill in one month.

### The New Rail-Mill at the Edgar Thomson Steel Works.

In the erection of the new rail-mill for the Carnegie Company by the late Mr. Wm. R. Jones, its superintendent and engineer, the work was started on a fresh piece of ground with everything new, and there were none of the drawbacks of some other works where old machinery has had to be removed. Like Mr. John Fritz, Mr. Jones believed that the first essential in steel rails should be high quality, and that, to attain the necessary perfection in structure, all blooms should be re-heated after leaving the

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blooming-mill, defective blooms being chipped at the hammer before being passed into the heating-furnaces.

The blooming-mill at the Edgar Thomson Works is the same which was, and is still at times, used in connection with the old rail-train. It is substantially the same as those described in connection with the Joliet and South Chicago Works. It is a three-high Fritz mill, with fixed rolls 40 inches in diameter, 7 feet 4 inches long, and is driven by an engine with 44-inch cylinder and 66-inch stroke. The ingot used is 16¾ inches by 19 inches at the butt. The general plan of the rail-mill, Fig. 5, Plate 8, shows the end of the roller-table, on which the bloom is brought from the blooming-mill. At the present time only one of the re-heating furnaces is used to heat those blooms which, from any cause, become very cold. In the original design and working the blooms were pushed in at the back of the furnace and pulled out at the front by charging-machines. The small number heated are at present pushed in and taken out by the same machine.

The train is divided into three sets of rolls each 25½ inches in diameter, formerly 24 inches. In the first set of roughers five passes are made. The rolls are driven by an Allis engine, with a 46-inch cylinder, 60-inch stroke, and running at 85 revolutions per minute. The second roughers are 77 feet from the first, and are three-high, being driven by a Porter-Allen engine with 54-inch cylinder, 66-inch stroke, running at about 90 revolutions per minute. The finishing-rolls are 120 feet from the second roughers, and are two-high, as only one pass is made in them. These rolls are driven by an Allis engine, with a 30-inch cylinder, 48-inch stroke, running at 70 revolutions per minute. All of the roll-stands or housings are open at the top, the caps being arranged to swing out of place by hand. When rolls are to be changed the whole set is taken out, with all the fixtures attached, a fresh set being ready to be put in place in the same manner. Many appliances are used to facilitate the work and save time during the changing of rolls.

The course of the rail is shown in Figs. 6. The bloom passes direct through the first pass in the first set of roughers to the first lifting-table, which is then lifted, the rollers reversed and the return pass made without turning. As the lifting-table is lowered, guides, which project up between the rollers, automatically turn the piece ready for the third pass, through which it is then drawn. As it is pushed over to the fourth pass it is automatically turned 90°. The course from the fifth to the sixth is the same as from the second to the third. Passing through the fifth the piece is carried



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direct over a fixed table into the sixth pass, being turned just before entering 90° by guides and the shape of the grooves in the rollers. The table on catchers at the side of the intermediate train is divided longitudinally, the part opposite the sixth and eighth grooves being pivoted at one end, the end next the rolls rising while the part of the table opposite the tenth pass is stationary. As the table is lifted to carry the piece from the sixth to the seventh it is turned automatically 90°. As it drops to the fixed table it is guided over to the eighth, which it immediately enters. Passing out on the tilting-table it is lifted and carried over to the ninth pass without turning, and drops to the tenth, through which it passes over the fixed tables to the finishing-train, in which it is given but one pass and taken immediately to the saws and thence to the cambering-machine and on to the hot bed. The rails are pushed from the hot bed to short driven rollers by which they are distributed to the various straightening-presses. After being straightened and drilled they are pushed out through openings in the side of the building to the inspection-beds.

When rolling 4-inch by 4-inch billets all the rolls are changed. Five passes are given in the first roughers, as in the rolling-rails; one pass in the second roughers and one in the finishing-rolls. The finished billet has each end cut off by the saws, and is passed directly across the end of the hot bed to a shear, in which the billets are cut while still hot to the required length. This shear has knives long enough and of sufficient power to cut four or five billets at once.

It may be said of the Edgar Thomson mill, as well as of the South Chicago Works, that its capacity is not yet known. So far it has been limited by the orders in hand, the section of the rails, and the capacity of the converting works to keep it supplied with ingots. The best month's work was in October 1894, when the mill produced 36,300 tons of rails. The best twenty-four hours' work was 1,945 tons of rails, and about 1,500 tons when running on billets.

### Plate-Mill of the Illinois Steel Company, South Chicago, Illinois.

The new plate-mill of the Illinois Steel Company at South Chicago has been put in operation within the last few months in connection with the new open-hearth plant of the same company. It is the largest and most complete plate-mill in the United States. The train, Figs. 8 and 9, Plate 9, consists of two stands of rolls of the Lauth three-high type; the first stand next to the pinions being 90 inches long, the top and bottom rolls 34 inches, and the

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centre rolls 18 inches in diameter, all of chilled iron. The outer stand has rolls 132 inches long, top and bottom rolls of steel 34 inches in diameter, and centre roll, of chilled iron, 21 inches in diameter. The mill will admit ingots 24 inches thick, and the table will deal easily with ingots weighing 7 tons or 8 tons. The mill is driven by a Porter-Allen engine, with 54-inch steam cylinder and 66-inch stroke. The speed of the engine is about 60 revolutions per minute. The ingots are brought into the mill from the steel works on wagons over a narrow-gauge line in front of the heating-furnaces, which are of the Siemens type. They are drawn in and out of the furnaces by an electric hydraulic charging-machine, similar in design to the machine, Figs. 7, Plate 9, referred to in the description of the Joliet Works. This machine takes the ingots from the furnaces and carries them to the extension of the tables, over which they are carried to the rolls. After the plate is finished it is carried by driven rollers to the cooling bed, on which the plates are moved, lifted and carried by four carriers, worked by electric motors, running on overhead lines, indicated by the four dotted lines. When marked and ready for shearing, the plates are deposited on the table in rear of the shear, into which they are carried and cut into short pieces as required, the edges being trimmed on one of the shears. The floor around these shears is commanded by two electric cranes of 5 tons capacity. These cranes are used for placing the plates in wagons on the line at the end of the building for shipment.

The plant is especially designed for rolling and dealing with large plates, which are cut into many smaller plates, thus saving a great deal of the scrap which would be made if the plates were rolled singly. The works have no slabbing-mill, the plates being all rolled direct from the cast ingot without re-heating. Very little trouble arises from imperfect plates; but, as would be expected, more scrap is made than if re-rolled slabs were used.

The Paper is accompanied by eight drawings, from which Plates 8 and 9 have been prepared.

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## Discussion.

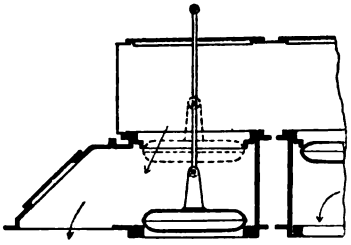
Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said both Papers were of a thoroughly practical and up-to-date character. It was very desirable that members, when referring to the Proceedings for information, should not find it of an obsolete kind. All would agree that Mr. Head's communication was a type of what a Paper for practical men should be, supplying just the kind of details required on the particular subject under discussion. Mr. Wellman's Paper gave a description of some of the most important rolling-mills in the United States, and it deserved the special thanks of the members, since it was the fourth Paper received from the other side of the Atlantic during the present session. He had great pleasure in proposing a vote of thanks to the Authors.

Mr. Head.

Mr. JEREMIAH HEAD remarked that the gas- and air-valves formed one of the most important details in open-hearth furnaces. Fig. 4, Plate 7, showed the first reversing-valve adopted by Mr. Siemens. It was simply a cast-iron "butterfly" valve with the producer-gas passing to the regenerators on the upper side, and the heated products of combustion passing to the chimney on the lower side. The heat was trying to the valves, and it was exceedingly difficult to keep them tight. Upon the original form improvements had been made on both sides of the Atlantic. The valve shown in *Fig. 1* was now largely in use in America. It consisted of a thick hollow disk, the periphery of which was formed to a double bevel. It rested on the lower seat at one end of its range, and when lifted it rested against the upper seat. It was not cooled artificially, but simply relied for stiffness upon its particular shape. The valve in *Fig. 2* had been recently introduced by Mr. Wailes, of Newcastle-on-Tyne, formerly of the Patent Shaft and Axle-tree Company, who called it the "siphon valve." There was a cup below full of water, and a funnel above it. In the position shown in the *Fig.*, and when filled with water, it prevented any gas escaping from the funnel-

*Fig. 1.*



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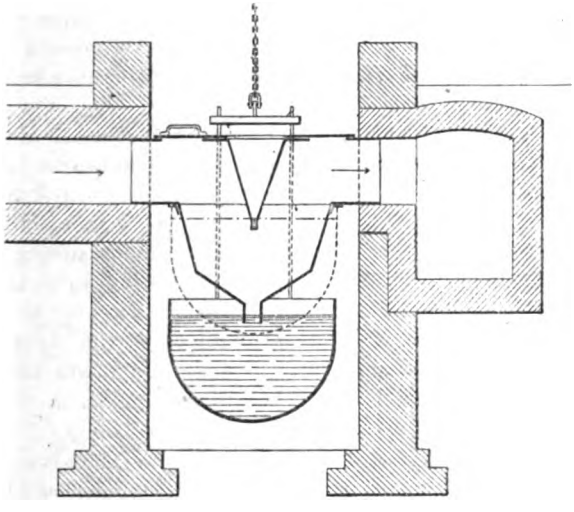
shaped orifice, but allowed it to pass along the flue. When it was lifted up until the water rose above the V-shaped mid-feather, it produced a water-seal and prevented the flow of gas altogether. It was therefore able to stop the gas or allow it to pass, according to its position. As the pressure of the gas was only equivalent to ½ inch of water, it was easily controlled in that way. The valve had been in experimental use in three works in Great Britain, and also on the Continent. In *Fig. 3* another valve devised by Mr. Wailes was shown. There were two valves on the same rod, but having independent motion, the top one being attached to a sleeve, and the bottom one to the rod. Their peripheries dipped in troughs which were kept constantly full

Mr. Head.

*Fig. 2.*



of running water. When the top valve was up and the bottom one down, the gas was passing from the producers through the regenerator to the furnace. If it was required to reverse, the lower valve would be lifted into a recess where it would be sheltered from the hot gases, and the top valve would be put down. By constant contact with water the valves could be kept fairly well in shape. *Fig. 4* was an improvement on the last mentioned valve, and was the invention of Mr. F. Mills, of the Wishaw Works in Scotland. The water was introduced from a pipe overhead down the stalk; it ran over the top of the valve and then down the vertical duct at the side. The peculiar section of the valve ensured that it was always in water. In the upper

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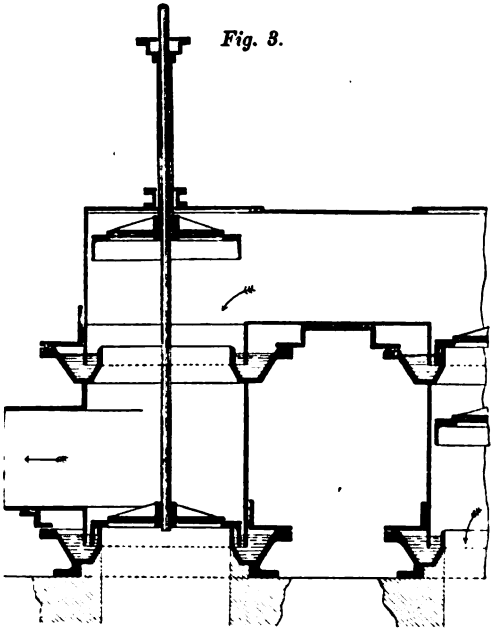
Mr. Head. position the seal was produced by the water it carried with it, and in the lower position by that contained in the trough below. It had been used for a considerable time. He believed it had been in use in all the eight melting-furnaces of the Stockton Malleable Iron Company's Works for about two years. A photograph he had received from Mr. Mills of a valve revealed after two years' work no distortion or deterioration.

He was glad to find that the remarks of Mr. Wellman to a great extent confirmed his own. He had spoken of the almost

*Fig. 3.*



universal practice in the United States of making plates direct from ingots without cogging, and confirmed the statement that the plates so made, or an overwhelming portion of them, were perfectly good on the surface and also stood the tests required in a very satisfactory way. In Fig. 9, Plate 9, he had somewhat departed from Mr. Head's typical plate-mill. The engine, and the mode of driving with three pinions, and the live-roller frames, were exactly the same; but another and larger mill was added. If the engine was strong enough, and also the pinions and spindles, there was no reason why that should not

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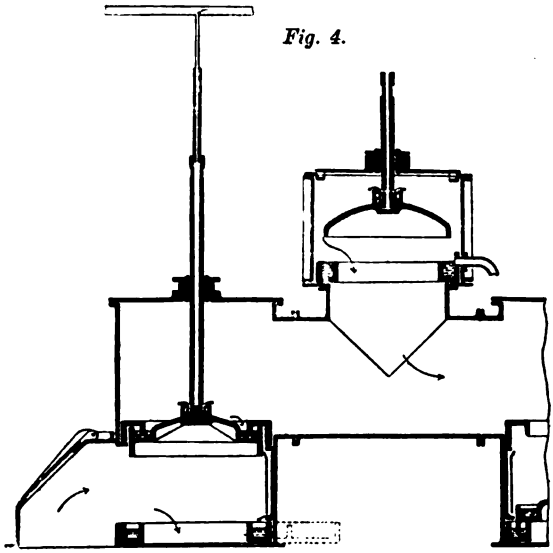
be done; but it should be understood that such a second plate-mill was not an essential part of the mill as were the two stands of rolls in the English type, where the plate first passed through the roughing- and was then transferred to the finishing-rolls. The second mill, as shown by Mr. Wellman, was not merely a finishing-mill for the first one; it was an absolutely separate mill. Both mills might be at work together, and might in that case make double the number of plates that one mill alone would produce. The second mill was made with longer rolls, so that he had the option of putting the narrower plates through the one and the broader through the other. In that way he was able Mr. Head.

*Fig. 4.*



to some extent to sort his orders. The horizontal charging apparatus which he had seen at work in the States had been referred to by Mr. Wellman. It certainly did its work very well. His only doubt was whether the time had not come when horizontally charged furnaces should be given up, and vertical heating furnaces used for all purposes. It was so much easier to lift heavy masses vertically in and out of apertures in the floor than it was to charge or draw them horizontally. Certainly Mr. Wellman had overcome his difficulties very well, but only by employing costly, heavy and elaborate apparatus which would be entirely unnecessary if the ingots were charged and

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Mr. Head. drawn vertically; and he saw no reason why that should not be done in all cases.

Mr. Webb. Mr. F. W. WEBB wished to refer to the length of rolls now being made. About thirteen years ago he had been anxious to try a locomotive boiler barrel in one plate; but at that time there was no mill in England or elsewhere that could roll it. He had accordingly built a set of rolls driven by two locomotive engines, having two 17-inch cylinders, and 24-inch stroke, coupled 35 to 1 with gearing, and he had succeeded in rolling a plate 11 feet wide. This he had used for the boiler, and he had recently had the pleasure of getting inside it and finding the barrel in perfect order; there was apparently very little pitting, and it seemed likely to work well for another seven or eight years. With regard to the method described in the Papers, he thought there was a tendency to make the ingots too thin, so as to avoid the process of hammering. He had already expressed his opinion as to the effect of using comparatively thin ingots for rolling plates. It was well known that ingots cast in a cast-iron mould had certain surface imperfections, and if the ingot was thin those imperfections formed a very large portion of the finished plate when it was rolled. His experience since he had made his first locomotive boiler of steel twenty-five years ago, had shown him that hammering was well worth its cost. It enabled an ingot to be taken much thicker than if it were rolled down direct, and consequently the surface imperfections of the finished plate were comparatively a very small portion of the whole. That, he thought, was one of the reasons of the success achieved with the locomotive boilers at Crewe. He had made more than four thousand, most of them by the Bessemer process, carrying pressures between 120 lbs. and 175 lbs. per square inch; and he had hitherto not had a single failure or a ruptured plate, though, of course, boilers had been "scrapped" from ordinary wear and tear. When he first began to make steel locomotive boilers he had been told, as Watt told Trevithick about high-pressure steam, that he ought to be put in gaol or in a lunatic asylum; but he was glad to say the prejudice had been overcome, and he thought very few engineers would now return to iron boilers. He would emphasize the importance of not attempting to cheapen plates too much by using too thin ingots; otherwise surface pitting would occur. With regard to rolling rails, the practice at Crewe was similar to that adopted in America. The ingots were cogged down, and were used on the London and North Western Railway in rails 60 feet in length; and sometimes, for passing

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over bridges, to avoid splices on the top of the bridge or in the centre of the opening, they could be rolled up to 100 feet or 120 feet, in fact as long as was required. The rails were now rolled in a reversing cog-mill, the last pass in which was opposite the first pass of the roughing-rolls of the three-high finishing mill. The ingots weighed 18 cwt. or 1 ton each, and they were rolled with one man at the back of the rolls. All the work of carrying about of the ingots was done on live rollers on each side of the three-high mill and cogging-mill. In the finishing-rolls the rails were sent up an incline so as to get the weight of the rail to help to pass it on the next pass. There was no trouble in the work. In that respect it was different from the American practice, as he did not like pushing the work on too quickly. He had found that rails rolled and sent out of the mill too hot had not the same wearing qualities as those that were rolled somewhat colder. From what he had heard in America, he could not help thinking that quickly-made American rails were not lasting as long as some that he had rolled and sent over to the United States. He had lately heard a good character of them, and he had been asked to give the analysis of the steel. He had replied that he thought the reason why the rails lasted so well was that they had not been rolled so hurriedly. Mr. Webb.

Mr. J. Wolfe Barry, C.B., Vice-President, asked Mr. Webb if the great weight of the rails on the London and North Western Railway had been found inconvenient for the men employed in the permanent-way department, or whether any special cranes were used for lifting the rails and placing them in position. He supposed each rail weighed about $\frac{3}{4}$ ton. Mr. Wolfe Barry.

Mr. Webb said they weighed 90 lbs. per yard. The permanent-way engineer used appliances for moving the rails, he believed. It required about six men to place them in the road. There was no practical difficulty in the way. The first rails of 60 feet long were put down, at his request, in the tunnel on the Festiniog Railway many years ago, and they had recently been taken up after a long life. No difficulty had been found with the joints. The 60-foot rail was now adopted for the main line, thus saving half the joints. Mr. Webb.

Sir William H. White, K.C.B., had read both the Papers with great interest, and considered them very valuable. There was one point in Mr. Head's Paper to which he should like to refer, because he thought it a matter of national importance. It was true that the open-hearth acid process was practically the only one in general use in Great Britain for manufacturing ingots for plates, Sir William White.

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Sir William White.

but it was true in a great measure by the choice of the manufacturers. The Admiralty, for example, were large buyers of steel, and for many years its specifications had permitted the use for ship-work of open-hearth basic steel on the same terms as open-hearth acid steel. There was nothing to prevent any maker from tendering for open-hearth basic instead of open-hearth acid, subject to the mechanical tests imposed. The invitation, however, had not been responded to. Before those terms had been laid down he had conducted a long series of experiments[1] on basic steel made both by the Bessemer and by the open-hearth process. The experiments had led the Admiralty to the conclusion that neither with Bessemer acid nor with Bessemer basic steel as used in riveted structures could the same certainty and uniformity be assured as by open-hearth steel, whether made by the one process or by the other. He knew that position had been challenged. He had seen quite lately a statement in a letter from a leading American steel-maker to the effect that in America the same difficulties had not been met with. He could only say, speaking of what he had repeatedly witnessed in experiments he had personally conducted, that in riveted samples of steel made by the Bessemer process, either acid or basic, less uniformity of result had been obtained under tensile test than had been obtained with similar riveted samples of steel made by the open-hearth process. But the point he wished specially to make was this: it was no doubt a matter of national importance that the ores which were most abundant in this country should be available for steel-making. The basic process allowed those ores to be used. The Admiralty, as a large purchaser, had allowed the use of basic steel made by the open-hearth process, and the manufacturers had not availed themselves of the opportunity. He presumed the only conclusion to be arrived at was, that under existing conditions and with existing plant it had been commercially preferable to continue the acid process. But it was a matter which, so far as the Admiralty was concerned, was entirely in the hands of the manufacturers. He thought it important that Mr. Head's statement should be qualified in the way he had mentioned.

Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said he knew that others had had a much wider experience of basic steel than himself; but in his own experience he had had more trouble and anxiety over the use of basic-steel plates for about six months

[1] Transactions of the Institution of Naval Architects, vol. xxix. p. 59; and Journal of the Iron and Steel Institute, 1892, p. 32.

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than he had had in twenty years' use of acid steel. In many orders for bridge-work received from abroad, he was expressly prohibited from using basic plates on account of the trouble experienced from the work, which had been thoroughly tested, arriving, after a long voyage, fractured in very strange and old-fashioned ways, such as Sir William White was familiar with when first using Bessemer steel plates for ships. He had had cases where a member of a girder, consisting perhaps of a vertical plate, two angles and a bottom plate, had fractured right through whilst being lifted by a crane out of the ship's hold. The result had been that he had had definite instructions in many cases not to use basic steel. On the other hand, he could not shut his eyes to the immense Continental experience in basic steel, and he could only infer that it was as Sir William White had said, that under present circumstances in this country the difference in cost was so little that the manufacturers had not trained their men to the necessary nicety in turning out the requisite quality of material. Up to the present time he agreed that the statement in Mr. Head's Paper was substantially correct. Sir Benjamin Baker.

Mr. F. W. Webb stated that during a practice of about thirty-three years in working the acid Bessemer process he had had no difficulty whatever in obtaining the uniform quality of steel that he required. As before mentioned he had made more than four thousand locomotive boilers beginning in 1872, and he had had no difficulty whatever. He had never had a single ruptured plate, or one that did not comply with the conditions required. The tensile strength of the steel was between 26 tons and 33 tons per square inch, according to the position in which it was placed in the boiler. He should like to ask Sir William White in what way the steel made by the Bessemer process had failed. He had always found that by putting good material into the vessel and taking care in the manipulation he could get good results, and he saw no reason whatever for changing his practice. He used both the Bessemer and the acid open-hearth processes, and had now 20-ton open-hearth acid furnaces at work for making rails and other things, but for steel plates he continued, with the greatest confidence, the acid Bessemer process. It was well known that good results could not be obtained from material containing sulphur or phosphorus; but with a careful selection of the best English hematite pig-iron and Swedish iron a uniform result could be produced. The whole of the steel plates used for H.M.S. "Captain," which unfortunately capsized in the Bay of Biscay, had been made by the acid Bessemer process. Mr. Webb

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Sir William White. Sir WILLIAM WHITE stated that the acid Bessemer process was in that case applied to quite minor and internal parts of the structure. All the main parts were of iron. The "Captain" was not a steel-built ship. He desired it to be distinctly understood that he was not denying in the least the possibility of making good steel by the Bessemer process. The facts he had mentioned, however, had been proved, and could be referred to in the Papers he had previously quoted.[1] A Paper on the testing of acid steel made by the Bessemer and by the open-hearth processes had also been contributed by Sir Nathaniel Barnaby.[2] Facts would be there found on which the Admiralty had proceeded in preferring the use of open-hearth steel on important parts of structures of ships where the riveting of several of the parts together was a necessity. He did not in the least impugn the Bessemer process, but the experience of the Admiralty did not point to the desirability of using Bessemer steel, whether acid or basic, in riveted structures in important parts of ships. He did not question the goodness or the perfection of what had been done at Crewe.

Mr. Webb. Mr. WEBB said all the steel plates in the "Captain" had stood a uniform test, and were made by the Bessemer process under his own supervision. He only wished to bear testimony to the fact that Bessemer steel could be made of uniform quality if good material were employed. He had used the Bessemer steel not only in ships, viz., the "Isabella" in 1878, the "Lily" and "Violet" in 1880, and the "Banshee" in 1884, the whole of the plates and frames of which were made of that material—the three latter being the fastest cross-channel steamers between Holyhead and Dublin—but in equally important structures, such as the Llandulas Viaduct, North Wales, which he had replaced in twenty-eight days after the memorable storm which washed away the seven-arch stone viaduct, on the 17th August, 1879; and he had no failures. The plates and frames of the three last steamers referred to were recently found so good that they had been re-engined with triple-expansion engines in lieu of the old low-pressure engines. The thickness of the plates in the locomotive boilers was between 1 inch and $\frac{3}{8}$ inch. The tube-plate was $\frac{3}{4}$ inch, the belly-plate $\frac{5}{8}$ inch, and the barrel-plate $\frac{1}{2}$ inch. The tube-plate would not be under tension. He might add that he had made a great many marine-boilers before they were all made of iron or steel, and

[1] *Ante*, p. 172.

[2] Journal of the Iron and Steel Institute, 1879, p. 45.

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had never had any failure or trouble with them until the Board of Trade stepped in and said that they were to be made in a certain way; then they had failed. For several years some of the London and North Western Railway Company's steamers had been running with steel boilers, and before they were required to be passed by the Board of Trade a failure was unknown. Mr. Webb.

Mr. THOMAS WRIGHTSON observed Mr. Head had pointed out that the general American practice was to adopt a non-condensing non-compounding engine. Where engines were designed to reverse, in the case of some rolling-mills, there might be considerations in favour of non-condensing and non-compounding; but he thought such practice was somewhat behind the time. Attention was now being generally directed to the question of compounding mill-engines, and great economies had thus been effected in the use of fuel. The compounding and condensing engine had achieved such vast success in marine practice that it would almost appear rolling-mill engineers had been backward in not following it up. In one works in which he was interested a large economy had been the result of compounding and condensing; and he thought it would not be long before other rolling-mill engineers would direct their attention especially to that economy. Mr. Wrightson.

Mr. A. MCDONNELL considered that copper was much cheaper and more reliable than steel for the fire-boxes of locomotives. He had received steel fire-boxes from America, but they had not answered well. The cost of fixing them was very heavy, and the length of time the engine was out of service while receiving a new fire-box was considerable. The life of a steel fire-box was certainly much less than that of a copper one. He did not, however, think that copper was so good or so durable as it was some twenty or twenty-five years ago. Mr. McDonnell.

Mr. J. H. R. WHINFIELD had during the past winter visited a number of rail-mills in Russia, and at one of them he had seen what was called a "mixer" or desulphurizer. He had been told it was an American device, but perhaps the Authors would say whether it was a common practice in America or not. He understood that it was adopted in order to secure uniformity of product; that the metal was run from the furnace into the "mixer," into which a large quantity was poured, and then run into the ingot-moulds to be afterwards worked down into rails. Mr. Whinfield.

Mr. JEREMIAH HEAD, in reply, desired to thank the members for the kind way in which his Paper had been received. The Mr. Head.

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Mr. Head. remarks of Mr. Webb represented what had hitherto been the general view of English platemakers, in so far as he defended strongly the plan of cogging ingots in a separate cogging-mill before they were rolled into plates. He even went beyond that, and defended hammering. That had been much believed in a good many years ago, but now it was entirely given up by English steel makers, except in very few cases. He knew one other advocate of hammering besides Mr. Webb. As to the use of thick ingots, and the value of a great amount of reduction in section between the ingot and the finished plate, in his Paper it was stated that this view was the one generally held in England, and one of his principal objects had been to show that it was not entertained in America; and that, with the exception of one case, plates were entirely rolled from flat ingots, generally not more than 1 foot thick. Some doubt had been expressed by Mr. Webb as to the surface which was produced by such a method, and also generally as to the quality as indicated by the tests which could be sustained. He had placed on the table two specimens taken from plates made by the open-hearth basic process for cutters of the Inland Revenue Department in the United States. The tests given in the Appendix were quite as severe as any applied in Great Britain. It would be seen from the two specimens that the plates had been folded over, and then cross-folded, so as to make a four-ply corner, which was hammered down perfectly flat, the whole operation being carried out cold. The surfaces were very good and there were no flaws. Those specimens were not selected; he had inspected a large number of plates in the United States, and he could not see any greater ratio of surface defects or faults than in English plates. He found from the returns of one of the large steel works in the United States with which he was associated, that during the last five months 96 per cent. of the plates rolled out perfectly sound to the sizes for which they were intended, leaving 4 per cent. for defectives, which included plates that were cracked, pitted, scabby, burnt, buckled, spotted, cobbled and blistered; and these were not entirely wasted, but were cut down into smaller sizes. He thought the number of the rejected plates was scarcely worth considering. The acceptance by the Admiralty of plates made by either of the two open-hearth processes, but not by either of the Bessemer processes, agreed with the practice in America; but the tendency there was for the open-hearth basic to supersede the open-hearth acid, notwithstanding that three-fourths of the pig-iron made in the northern district was suitable for Bessemer purposes. At the

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Carnegie Company's works, for example, four or five years ago there was only one basic-lined open-hearth furnace, but now there were sixteen. Acid-lined furnaces had been abandoned for plate-making and other things, in favour of open-hearth basic, the reason being, as he had explained, that it gave much greater latitude in the materials which could be employed. No matter what impurities went with the charge into the furnaces, the product could still be controlled and plates brought out of such a quality as those shown on the table. The fact that English plate-makers were almost all for the open-hearth acid process, was to some extent an accidental circumstance. English steel-works were mainly on the coast; there were excellent facilities for bringing the good and cheap ores of Spain to English sea-ports; and the steel-making trade for ship-building and boiler-making purposes was originally based on the supply of hematite pig-iron obtained from that foreign ore. The trade having once been established steel makers were reluctant to run the risk of trying new experiments and so had followed suit one after another in employing the acid process. It would also be remembered that in the earlier days both Lloyd's and the Admiralty naturally preferred what they had most experience of. Good plates could be made by the open-hearth acid process, and they preferred that mode of making them, being suspicious of anything that had the name of basic. That, no doubt, had a very discouraging effect on the growth of the basic steel trade of all kinds which utilized native ores. He believed that was now passing away, and he was glad to hear the statement of Sir William White that the Admiralty was quite willing to take open-hearth basic plates for its own purposes. When, however, a trade had been established as long as the open-hearth acid trade had been, and the workmen and the agents were accustomed to it, it was not easy to alter it. In fact, the workmen formed the great difficulty, and resisted its introduction. In speaking of the trouble arising from basic steel, the President probably alluded to basic Bessemer steel, which had come from the continent, especially from Germany, in large quantities. His statement was undoubtedly true that some of those products had given a good deal of trouble; but he believed that both in England and in America there had been a great improvement during the last few years, and there could be no doubt that excellent steel was made from any of the four processes. That accorded with the observation of Mr. Webb, who had made plates from the Bessemer acid process for many years without any trouble. It should be remembered that at Crewe the best prices were paid, and the best material

Mr. Head.



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Mr. Head. and labour were employed, under thorough supervision. He was inclined to think there was more risk of variation in the Bessemer than in the open-hearth processes. The operation was much more brief, and there was less chance of watching and doctoring the charge over a considerable length of time, and testing it; it was therefore less certain unless there were great facilities and the excellent superintendence and judgment available at Crewe. In the United States, rolling-mill engines were not compounded, because they were very simple, often of the Corliss type, where there was a considerable amount of expansion in one cylinder. It should also be remembered that they had an automatic expansion-gear, which, if needed anywhere, was needed in a rolling-mill engine, where the load factor was continually varying. That, perhaps, became a simpler thing where there was one cylinder than where there were more. In regard to condensation, the condensing water required was generally at least thirty times the weight of feed-water; and where, as in the case of the one referred to, several engines were exhausted into one common condenser in a steel-works, the amount of water was probably more like sixty times than thirty. Where the works were by a river, as in the case mentioned, and a large duct had been brought a considerable distance from it for the purpose of condensing, it became perfectly possible; but it was somewhat costly, though no doubt it paid in the end. There were many ironworks situated where that large supply of water could not be obtained, and that, he presumed, was the reason why condensation was not more frequently adopted. In the large ironworks in the Middlesbrough district, on the south side of the railway between Middlesbrough and Redcar, none of the blowing or other engines were condensing. The difficulty was that there was not enough water. As to the duration of steel as against copper for the inside fire-boxes of locomotives, he might mention that in the United States (where the length of railways was six times that in Great Britain, and the locomotives, though not quite in the same proportion, were much more numerous) the inside fire-boxes were all of steel, and they seemed to give good results. These fire-boxes were now improved, however, by the open-hearth basic process, and the steel from which they were made was very similar to that shown upon the table. Every locomotive superintendent had his specification both in regard to tensile tests and chemical tests. Whether they lasted longer or not he was not in a position to say, but he could assure Mr. McDonnell that steel was increasing in reliability and manageability. Those two circum-

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stances in time might reverse the fashion in this country. As to the question of mixers and desulphurizers, Mr. Whinfield appeared to refer to the desulphurizers as used between the blast-furnace and the converter or open-hearth furnace, rather than between the latter and the ingot-moulds. These were large brick-lined vessels into which the molten product of a number of blast-furnaces was poured, and from which the product going to the converter or open-hearth furnace was taken. By means of charging a certain amount of manganiferous ores into the blast-furnaces, or into one of a series of blast-furnaces, and mixing them in the mixer, the manganese affected the sulphur and reduced it to about one-half. Those desulphurizing mixers were used in the northern district; at the Barrow Steel Works, at Bolckow, Vaughan & Company's Works and at the North Eastern Steel Works, and they were also used in almost all the recent works in America. They were of the greatest possible advantage. Although in Great Britain they had generally been used as preliminary to the converters, they were used in America for serving open-hearth furnaces also, with good results. It enabled white pig-iron to be used containing low silicon, which would otherwise have high sulphur. It was possible to minimize the sulphur, while retaining the advantage of low silicon, which was a matter of great importance. Mr. Head.

## Correspondence.

Mr. G. W. Dickie remarked that Mr. Head, in referring to the different methods of producing mild steel, appeared to assume that an equally good quality of steel could be produced by the open-hearth basic process from impure and cheaper pig- and scrap-iron as could be produced by the open-hearth acid process, using the higher grades of pig- and scrap-iron necessary for that process; and that the basic-lined furnaces enabled manufacturers to draw supplies from a wider market, and at lower prices. "Miscellaneous scrap-iron, which is usually cheap, can be utilized."[1] He had had occasion to use large quantities of shapes, in ship-framing, requiring severe working, produced by steel-works adjacent to the ship-yard of the Union Ironworks, San Francisco. These were made until about two years ago by the open-hearth acid process; the pig- and scrap-iron being carefully selected for the purpose. Basic-linings had then been introduced, to enable large quantities of rejected scrap to be used, and while the resultant product Mr. Dickie.

[1] *Ante*, p. 134.



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Mr. Dickie. passed inspection, both as to chemical and physical tests, yet the material thus produced was almost entirely lacking in those qualities of endurance under working that was so distinctive a feature in steel shapes made from selected materials by the open-hearth acid process, and he considered this had been the experience of others using steel shapes for structural purposes, where the material must undergo much working to prepare it for its place in the finished structure.

Mr. Gillott. Mr. THOMAS GILLOTT asked whether with one stand of three-high rolls, cooled by water, the thicknesses could be maintained uniform across the width, and the surfaces of the plate satisfactory, without frequently dressing the rolls. For flanging-plates the dies must be tight, otherwise the flanges would not be true, so that a very small variation in the general thickness, or local lumps, would either tear the plates or burst the dies. For the removal of scale or cinder from the under surface of plates whilst being rolled, he had not found either steam- or air-jets effectual, as only the thinnest scale was blown away. The use of cogging-rolls instead of hammers for slabbing ingots was doubtless more economical, but the best use had not always been made of the hammers, probably because it was not advisable to weld on a staff for working a steel ingot. The slabs used for making best Yorkshire iron boiler-plates had a considerable amount of edge work both on sides and ends, besides which, the four corners of the slabs were flattened out so as to reduce the waste in shearing the plates; and the number of plates from the slabs could show even a better result than given on p. 21, good as these undoubtedly were. With edge work as described, 1 inch sheared off would leave a good plate, and by reason of the corners being spread in the slab there was little or no convexity in the sides of the plates or concavity at the ends, so that the Yorkshire iron plates were always sound at the corners so far as the quality of the iron was concerned. He asked what would be the average width sheared from cogged blooms and rolled-off ingots, in plates 6 feet to 7 feet wide, to leave sound material. The use of a single stand of rolls had an enormous advantage in saving the time of transfer for finishing at chilled rolls at a stage when time was most valuable. He could hardly regard the plate-mill, Fig. 8, Plate 7, as quite standard English practice; if, as appeared from the illustrations, the top chilled roll was unbalanced, and, consequently, did not require to be driven, and was allowed to fall on to the lower roll at each pass. He preferred to balance both grain and chilled rolls in large mills to avoid destruction of the surface of the latter, but when

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balanced they required to be driven also. In the older plate-mills in England the chilled rolls were invariably loose so as to run by friction only; but the limit for this method was passed for rolls of such a size as 30 inches diameter, 8 feet long, and weighing about 10 tons. Referring to *Figs. 9*, p. 143, he asked whether for squaring a slab any variation was provided for in the geared screws to allow of unequal screwing when required. About twenty-one years ago he had designed and erected the large plate-mill at the Farnley Iron Works, near Leeds.[1] A 20-ton travelling crane worked over the whole of the mill floor, the floor-plates were large (8 feet by 4 feet) and heavy, and holes were cast in them to receive pillars; so that when a large plate was rolled it could be reared by the crane against the temporary pillars to be examined and sounded for defects on both sides before shearing. The shearing bogie was arranged on four castor-rollers, and for long plates two bogies could be used. None of the arrangements described appeared to provide for the turning-over, or rearing, for examination of plates before shearing; and when a plate, by reason of some slight defect, could not be used for the purpose or size it was originally rolled for, the examination often enabled a better use to be made of a waster than would otherwise be the case. The Author of the first Paper would, doubtless, be aware that the old plate-rollers not only turned their rolls hollow, but also kept the bottom roll smaller than the top to avoid "collaring." For reversing mills, he preferred all the rolls to be of uniform diameter, as a tearing action on the material rolled was often seen when the top rolls were larger. As to the springing of the rolls, he would expect that a 13-foot roll would spring so as to leave a plate of full width $\frac{1}{8}$ inch thicker in the middle instead of $\frac{1}{16}$ inch as stated. One of the first orders executed in the mill at Farnley included plates 10 feet square and $\frac{7}{16}$ inch thick, and about thirty were rolled. He did not find one that was not $\frac{1}{8}$ inch thicker in the middle than at the sides, and some slightly exceeded this. Neither Paper described any provision for turning plates during rolling, and it might be inferred that although some large plate-mills were described they were not often used for the full widths they could roll. The usual course followed was to roll out the width of the slab to the width of the plate, plus shearings, then turn round and finish to the length. When wide plates were rolled the turning usually occurred when the plate was between $\frac{7}{8}$ inch and $1\frac{1}{2}$ inch thick for $\frac{1}{2}$ inch or $\frac{3}{4}$ inch finished thicknesses; and any loss of

Mr. Gillott.

[1] *Engineering*, 3 November, 1876.

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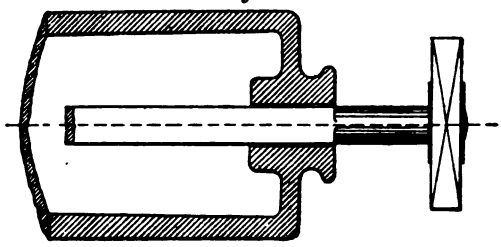
Mr. Gillott. time and heat at this stage was of vital importance. The plates above mentioned were made from slabs about 6 inches thick, and in thirty-five or thirty-six passes, half of which were before turning and half afterwards; it was not only necessary to turn quickly, but such plates must be central with the length of the rolls after turning, and when the total time of rolling was four minutes fifty-five seconds, or five minutes, the plates were approaching a black heat when finished; when two minutes were occupied in turning the plates and placing them central with the rolls, the rolling could not be finished at a red heat. In this case slung levers were used for turning, as a turntable bogie was not satisfactory. Although the shearing of thick plates distorted the edges and injured steel, an attempt made about twenty-five years ago to cut plates when hot by circular saws had proved a complete failure.

Mr. Pettigrew. Mr. CHARLES PETTIGREW, of Evanston, U.S.A., observed that the tonnages given by Mr. Wellman for the Joliet Mill, for the year ending May, 1895, had been much improved. During the year ending December, 1895, the best twelve hours' work had been 828 tons; the best month's work, 31,100 tons; and the average work per turn, 595 tons; the average for December being 691 tons.

Mr. Wawn. Mr. CHARLES WAWN noticed that in both Papers allusion was made to "carrying" or "feed" rollers. These were now in general use, although there had at one time been much prejudice against them. This had arisen from frequent breakdowns, due in a great measure to the fact that some of the earlier roller-tables had been designed without sufficient regard to the heat, dirt, blows and other

*Fig. 5.*



hard usage to which they were exposed. The roller-table was now, however, recognised as an important adjunct, and all mechanical details were carefully thought out. A peculiarity in the carrying rollers in the plate-mill he had designed five years ago for the Patent Shaft and Axle-tree Company was shown in *Fig. 5*. A small lip was cast on the end of the boss by which most of the fine hard scale, which might otherwise have reached the bearings,

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was intercepted and fell to the ground as the roller revolved. In this case the roller-table on each side of the mill was made to traverse. The rollers were not driven by bevel gearing, but by a train of ordinary spur-wheels. The intermediate wheels were mounted on axles, instead of running loose on pins. Mr. Wawn.

Mr. HEAD remarked, in reply to the Correspondence, that there was certainly less variation in the thickness of plates rolled by three-high mills with constantly wet chilled rolls, than in those rolled in two-high chilled rolls worked hot and dry. The wear of the rolls was naturally proportionate to the work done by them in either case, and so was the dressing required. As regarded the allowance for shearing, the extra width necessary where the rolling was direct could easily be calculated from the Table of yields given in the Paper. No variation need be provided for in the geared screws for taking out the taper of the ingot. That was done by corner rolling in the way he had described; but if the roller found the two sides of the plates, as currently rolled, not exactly the same thickness he would stop and adjust the screws. There was a very effective arrangement in American mills for turning over the plates for examination; it was placed between the rolls and the shears. He had omitted reference to it, because the Paper had already exceeded the usual limits. Notwithstanding Mr. Dickie's somewhat unfavourable experience of basic open-hearth steel, his own confidence in that material was not shaken, nor was he in the least inclined to modify what he had expressed. He noticed that the steel-makers alluded to had not used basic hearths very long. Probably they would in time arrive at the excellent and uniform results now so generally obtained where the process had been fully developed, and where the appliances and arrangements had been fully perfected. Mr. Head.

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12 May, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The discussion upon the Papers by Mr. Jeremiah Head and Mr. S. T. Wellman was continued and concluded.

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19 May, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

It was resolved—That Messrs. J. Angus, G. Chatterton, W. Santo Crimp, A. Honeysett, F. Hudleston, C. S. T. Molecey, W. F. Pettigrew, A. W. Szlumper, John J. Webster and L. S. Zachariasen be appointed to act as Scrutineers, in accordance with the By-Laws, of the Ballot for the election of Council for the year 1896–97.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

*Member.*

WALTER LONGLEY BOURKE.
THOMAS KIRKLAND.
ROBERT MACALISTER.
FREDERICK WILLIAM MCCULLOUGH.
CHARLES DONALD NAPIER PARKER, B.E.
CHARLES EDWIN SPOONER, B.E.
ARCHIBALD ALEXANDER SWAN, B.Sc.

And that the following Candidates had been admitted as

*Students.*

HAROLD GWYNNE ALLEN, B.A.
FRANK ARMSTRONG.
HECTOR ÉLIE DE BOISSIÈRE.
WILLIAM BELLINGHAM CARTER, B.E.
HAROLD OFFICER CLARKE.
ROBERT WHITEHEAD HAMMOND.
JAMES MORTON KERR.
WILLIAM NEWSAM MCCLEAN, B.A.
WALTER JAMES NEWBALD.
HENRY EOGHAN O'BRIEN.
SAMUEL BENJAMIN PRIEST.

The Candidates balloted for and duly elected were: as

*Members.*

THOMAS LYON CHUBB.
WILLIAM VAUX GRAHAM.
CARLOS MASCHWITZ.

*Associate Members.*

THOMAS CLIFFORD AVELING, Stud. Inst. C.E.
ARTHUR MOWBRAY BERKELEY.
SIDNEY JAMES BIRD.
HERBERT CLARKE.
WILLIAM CHARLES COPPENTHWAITE.
HENRY GEORGE COVENTRY.
HENRY CLAUDE JOHN EDWARDS.
FERDINAND FORTESCUE FAITHFULL, Stud. Inst. C.E.
RICHARD CRAIG FARRELL, Stud. Inst. C.E.
STAFFORD GAFFNEY, B.E.
WILLIAM HEMINGWAY.
WILLIAM HENRY HOPKINSON.
JOHN FREDERICK CAMPBELL KIRBY.
HUMPHREY ALEXANDER MINCHIN.
ARTHUR DURY MITTON.
EDMUND NUTTALL.
ARTHUR PEIRCE.
JAMES POLLOCK, Jun., Stud. Inst. C.E.
GERVASE HENRY ROBERTS, Stud. Inst. C.E.
WILLIAM GARNEYS WALES, Stud. Inst. C.E.

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(*Paper No. 2967.*)

# "The Magnetic Testing of Iron and Steel." [1]

By JAMES ALFRED EWING, F.R.S., M. Inst. C.E.

THE magnetic testing of iron and steel has become a matter of considerable industrial importance; from being a mere laboratory experiment, interesting only to students of physical science, it has quickly passed to rank as an ordinary operation in engineering comparable with the mechanical testing of materials. Makers of dynamos and transformers require not only that the iron with which they are supplied shall be magnetically suitable, but that its properties in this respect shall be specifically ascertained. They realise that large variations in magnetic quality result from apparently trifling differences in composition or in treatment. Iron and steel makers have shown themselves alive to these considerations, and, guided by the results of magnetic tests, have succeeded in producing material enormously superior to anything that could be obtained even two or three years ago. Especially in steel castings for dynamo magnets and in stampings of sheet-metal for transformer cores the advance has been remarkable. In regard to dynamos this has resulted not only in improved efficiency and economy but in giving designers a greater latitude as to form, by the substitution in many cases of castings for forgings. In regard to transformers, the saving in power brought about by the use of magnetically better iron is so great as to affect largely the general efficiency of alternate-current systems of electric distribution. A dynamo may still be more than fairly efficient even when the iron is of indifferent magnetic quality. But in a transformer the waste of energy due to magnetic action on the iron is liable to be so large, under the conditions in which transformers are commonly used, that any considerable improvement in the quality of the iron is of vital importance. The value of magnetic tests in this connection

[1] The discussion upon this Paper was taken in conjunction with the following one by Mr. Parshall.

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will be evident from examples to be given later in the Paper. The Author's intention is to describe and discuss some practical methods of carrying out magnetic tests, applicable to the material used in dynamos and transformers; and further, to state the results of a few representative tests, mainly selected from his own practice.

Before proceeding to describe methods of testing in detail it may be well to recall the conventions which are adopted in stating the magnetic quality of materials, as well as one or two of the principles on which methods of testing are based.

*Magnetic Induction and Magnetizing Force.*—Imagine a turned ring of iron wound with a magnetizing coil of insulated wire, the turns of which are uniformly distributed all round the ring. When a current is passed through the coil a state of magnetization is set up in the ring. This state is numerically expressed by the number of lines of force which would be found in a crevasse cut radially through the ring, the number being reckoned per square centimetre of cross-section. This number is called the Magnetic Induction, and is denoted by the symbol B.

The magnetic induction is said to be produced by the Magnetising Force of the current in the coil. The magnetizing force is simply proportional to the current and to the number of turns (per unit of length) in the coil. It is expressed by the symbol H, and its numerical value is $0{\cdot}4\pi$ times the number of ampere-turns per centimetre, or $\frac{0{\cdot}4\pi CN}{L}$, where C is the current in amperes, N is the total number of turns in the coil, and L is the circumferential length in centimetres. Since L has different values round the outside and round the inside of the ring it follows that H has correspondingly different values at places near the inside and outside. By taking the middle value of L a mean is obtained for H, which is the true value of H in the middle of the section. If the mean diameter of the ring be called D, the mean circumference is $\pi$ D, and hence the expression for H may conveniently be written

$$\frac{0{\cdot}4\,CN}{D}.$$

*Magnetization of a Rod.*—A long rod, uniformly wound with a magnetizing coil, is less simple from the magnetic point of view than a ring, for in the ring the magnetic circuit is complete within the iron, whereas in the case of a rod, the lines of induction have to close themselves by returning partly through the

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surrounding space and partly through the rod itself. Thus the magnetization of the rod may be said to react upon itself, weakening the magnetizing force, which is no longer equal to $\frac{0{\cdot}4\pi C N}{L}$ (L being the length of the rod in centimetres), but to something less than this. The extent to which it is less varies in different parts of the rod, and consequently the magnetization of the rod is not uniform. At any point in the rod the true magnetizing force is that due to the coil, or $0{\cdot}4\pi$ times the ampere-turns per centimetre, less a quantity which the Author has elsewhere called the "self-demagnetizing force";[1] the existence of which arises from the fact that the rod has ends. The longer a rod is taken the less influential does the self-demagnetizing force become; and when the length of the rod is some hundreds of times greater than its diameter it becomes practicable to neglect, without serious error, the existence of the self-demagnetizing force in the central portions of the rod, and to treat the magnetising force there as if it were due only to the current in the coil. With shorter rods, however, the influence of the ends is too considerable to be neglected. When the length is less than a hundred diameters it is not even roughly true that the magnetizing force is $0{\cdot}4\pi$ times the ampere-turns per centimetre. It is less by an amount depending on the magnetic induction, for the more strongly the rod becomes magnetized, the more strongly do the ends react to oppose the magnetization. If the influence of the ends in producing self-demagnetizing force could be allowed for by calculation such a rod might properly be used as a test-piece; but the distribution of magnetism in a rod of uniform section is so far from simple that it is not practicable to calculate the true magnetizing force at any point within it. Hence, experiments on short rods are not available, without an important modification to be mentioned immediately, as a means of examining the relation of magnetic induction to magnetizing force in iron.

*The Ellipsoid.*—One way in which the conditions of the experiment can be modified to allow the true value of the magnetizing force to be determined is to give the rod a special form, namely, that of a long ellipsoid with circular cross-section. The mathematical theory of magnetism shows that this form has the peculiarity of causing the self-demagnetizing force to be uniform at all points when the magnetizing force due to the coil is uni-

[1] "Magnetic Induction in Iron and other Metals," p. 33 *et seq.*

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form. Hence the true magnetizing force in this case is readily found by subtracting from the quantity $\frac{0{\cdot}4\pi CN}{L}$ a term which is proportional to the magnetization of the rod. The term in question is found by multiplying the magnetization by a factor which depends on the ratio of the long to the short axis of the ellipsoid.[1] The use of long ellipsoids for test-pieces is entirely satisfactory so far as regards the intelligibility and precision of the results. Its great drawback is, of course, the expenditure of skill and time needed to give the specimen its proper form. It is important that the ellipsoid be of considerable length in comparison with its transverse diameter, otherwise inaccuracy in the geometrical form is liable to cause much error in the results. Tests with ellipsoids have hitherto been made rather for purposes of physical research than for those of the workshop, the requirements of the engineer being in general sufficiently met by one of the less refined processes to be described below. But it may be questioned whether any other method is capable of equal accuracy. At the Imperial German Physicotechnical laboratory ellipsoids are now used for tests requiring particular care.

*Bar and Yoke Methods.*—Another and practically a most useful way by which short rods may be made available as test-pieces is the method of the yoke, due to Dr. John Hopkinson. A rod of uniform section is used, and its ends are connected magnetically by being imbedded in a massive yoke of the softest iron. The magnetizing coil is wound on the rod only. The yoke affords an easy return-path for the lines of induction; it completes the magnetic circuit, and prevents the lines of induction from leaving the bar at intermediate points. It avoids or greatly reduces the reaction which has been mentioned as existing in a short rod. The effect is that when a yoke is used the magnetizing force acting on the rod is practically uniform along the whole clear length, and is only a little less than the value calculated from the current in the magnetizing coil, namely, $\frac{0{\cdot}4\pi CN}{L}$. A form of yoke will be later described which allows the correction to be determined, namely, the amount to be subtracted from this expression to give the true magnetizing force acting on the rod. When the correction in question is applied the method of the yoke may be made as rigorous as can be wished.

[1] For particulars and values of the factor see "Magnetic Induction in Iron and other Metals," pp. 31-32.

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*Measurement of the Magnetizing Force H.*—In most instances, whatever be the form of the sample, the primary object of the test is to determine the relation of the magnetic induction B to the magnetizing force H. The magnetizing force is found from the current in the magnetizing coil, subject (except in the case of a uniform ring) to a correction which depends on the observed value of the induction. It will be convenient to express the magnetizing force as $H = H' - K$, where $H'$ is the value of $\frac{0{\cdot}4\pi C N}{L}$, or the force reckoned for the current only, and K is the correction required in consequence of the fact that the specimen is not an endless uniform ring. When such a ring is used K is zero and H is identical with H'. Any breach of continuity in the ring, however, has the effect of reducing H by requiring the application of a correction K. In some experiments a narrow gap has been made in the ring, and for such a gap the appropriate value of K can be readily calculated when the width of the gap is known in relation to the whole circumferential length of the ring.[1] In other experiments the ring has been cut in two halves, and the ends brought into close contact. The Author has shown elsewhere[2] that the presence of a joint in the magnetic circuit, even when the surfaces which touch are faced as accurately as possible, has an effect which requires the introduction of a correction K before the true magnetizing force can be deduced, and that the amount of this correction, even for the most perfect mechanical joint, is by no means negligible. In tests where a yoke is used, any joint, either in the yoke or in the bar, tends to increase K.

*Measurement of the Magnetic Induction B. The Ballistic Method.*—To measure the magnetic induction B, the ballistic method is the most common. A coil, generally consisting of a few turns of fine wire, is wound on the specimen (preferably under the magnetizing coil), and is connected to a ballistic galvanometer. When any sudden change is made to take place in the magnetism of the piece, a transient current is produced in this coil, and gives rise to a corresponding swing in the galvanometer. To cause the swing to be proportional to the change of magnetism, it is essential that the change should in each case be so quickly completed, in comparison with the slowness of the swing, that the swing will scarcely have begun before the change of magnetism has finished. When the cross-section of the iron

[1] "Magnetic Induction in Iron and other Metals," p. 264.
[2] *Ibid*, p. 273.

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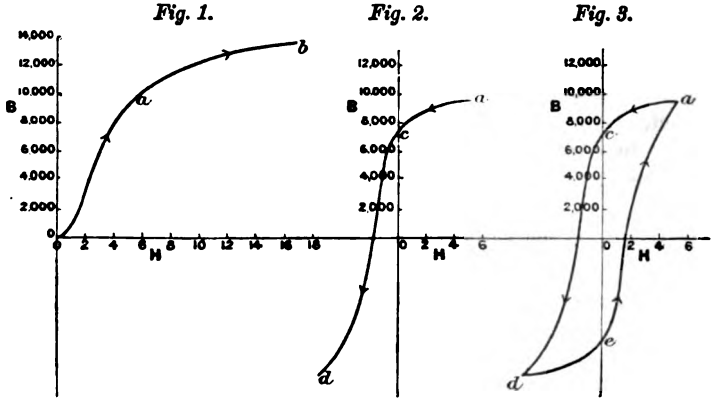
operated on is large, this condition is not easily satisfied, for the changes of magnetism then happen so slowly that it is scarcely possible to give the galvanometer a sufficiently long period of swing. When a massive yoke is used, the same objection holds to the use of the ballistic in its ordinary form, for although the bar forming the test-piece may have a small section, the return circuit through the yoke takes a comparatively long time to fully establish itself. The d'Arsonval type of galvanometer, with a coil swinging between the poles of a permanent horse-shoe magnet, is particularly convenient for ballistic work, not only on account of the constancy of its indications, and the fact that it is not affected by external maguetic forces, but especially because the swinging coil is readily brought to rest after each observation by the simple use of a short-circuiting key.

*Relation of Induction to Magnetizing Force.*—The value of the




induction B which is produced by applying any magnetizing force H is found to depend, not merely on the value of H then applied, but on the preceding magnetic history of the iron. When the iron is not previously magnetized, and magnetizing force, increasing step by step, is applied to it, a relation is found between the two quantities H and B which is exemplified in the curve *o a b* of *Fig. 1.* This is the typical magnetization curve or "permeability" curve, the word permeabilty being used to designate the ratio of B to H at any stage in this process. The permeability, or $\frac{B}{H}$, is generally written by the symbol $\mu$. If, however, the magnetizing force H, after being raised to any value, is reduced to zero and then re-applied in the opposite direction, the curve of B and

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H takes a form such as is shown in *Fig. 2* by the line *a c d*. And if the magnetism of the piece is periodically reversed (as happens, for example, in the core of a transformer) the process, after a few repetitions, becomes strictly cyclic, and is represented by a closed figure such as *a c d e a*, *Fig. 3*. A few repetitions are necessary to establish a cyclic state, for it is found, in general, that the first reapplication of the original magnetizing force does not completely restore the magnetism, and it is only after several journeys that the return curve comes exactly to the starting point. There is, however, no important difference of position between the locus of points such as *a* in *Fig. 3*, for cycles performed with various maximums of magnetizing force, and the curve of *Fig. 1*. Hence, to obtain the permeability curve the process is often followed of subjecting the iron to reversals of magnetizing force, and taking half the change of magnetism in a reversal as equivalent to the magnetism which the same force would produce in a previously unmagnetized piece.

*Hysteresis and Permeability.*—Cyclic curves, such as *Fig. 3*, exhibit the effect of what the Author has called magnetic hysteresis, that is to say, the tendency which the magnetism shows to persist when the magnetizing force is changed. They have the important practical property that the area they enclose measures the work done in carrying the iron through the corresponding cycle of magnetization. The measure of this work, in ergs per cubic centimetre of the metal, is $\frac{1}{4\pi}\int \mathrm{H}\,d\,\mathrm{B}$, or, in other words, $\frac{1}{4\pi}$ into the area enclosed by the B–H curves.

For iron that is to be used in dynamo-magnets the important thing to know is the relation of B to H in the curve of *Fig. 1*, especially in the upper region of that curve, since the magnetization is always in practice so strong that B exceeds 10,000 C.G.S. units. For transformer plates, on the other hand, a knowledge of the permeability of the metal under weak magnetizing force is useful, but the all-important quantity with which tests concern themselves is the hysteresis, namely, the work spent in carrying the iron through its magnetic cycle. The two quantities, permeability and hysteresis, have no essential connection, although in general it is found that a material with small hysteresis has high permeability. In dynamo-magnets permeability under strong magnetizing forces is the desideratum, and hysteresis is immaterial; in armature stampings high permeability and low hysteresis are both desirable; in transformer stampings hysteresis

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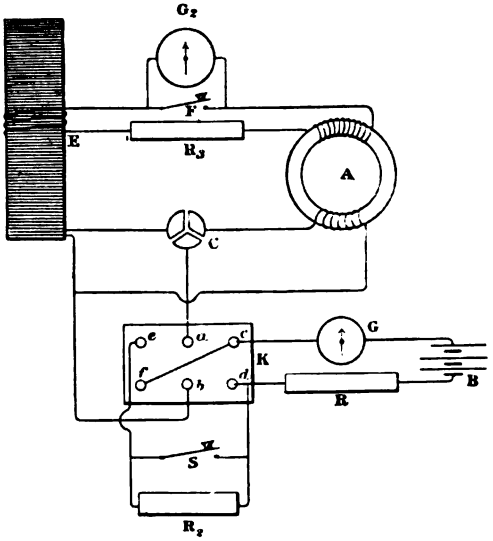
is so much the main consideration that if a specimen is good in this respect, its permeability may be taken for granted. The quality of transformer plate in regard to hysteresis may be tested directly, by means of a special apparatus which will be described below, but it may also be determined by the more laborious process of tracing the B–H curve in cycles of magnetization and measuring the enclosed area.

*Application of the Ballistic Method.*—A convenient arrangement for carrying out ballistic tests, which enables either the simple curve of *Fig. 1* or the cyclic curve of *Fig. 3* to be determined, is

*Fig. 4.*




ARRANGEMENT FOR BALLISTIC TESTS.

shown in *Fig. 4*, where A is the sample under test. The magnetizing current from the storage battery B is regulated by the adjustable resistance R, and measured by the ampere-meter G. It passes through the key K, which, when thrown over to one side, places *a* in contact with *c* and *b* with *d*, and when thrown over to the other side places *a* in contact with *e* and *b* with *f*. So long as the short-circuit key S is closed, this simply reverses the current, but when it is opened the effect is that the reversal of K not only changes the sign of the current, but also alters its amount by throwing in the supplementary adjustable resistance $R_2$. A very convenient form for $R_2$ is that of a liquid rheostat, formed by

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lowering a pair of amalgamated zinc plates, connected as a horse-shoe, into two adjacent vessels containing a dilute solution of sulphate of zinc. The induction coil on the specimen is connected to the ballistic galvanometer $G_2$, and in series with it is a large permanent resistance $R_3$ and also the secondary of an induction coil without an iron core (E) which is used as a means of standardizing the ballistic galvanometer. A short-circuit key F is kept closed except when a swing of the galvanometer is about to be produced. A three-way key at C allows the magnetizing current to be sent either into the primary of E, or into the magnetizing coil of the ring under test. To obtain a plain magnetization curve such as *Fig. 1*, S is kept closed, and the resistance $R_2$ is not used. The current is brought to any desired value by means of R, and is then suddenly reversed several times. The effect of a reversal on the ballistic galvanometer is observed, and half of this is taken as corresponding to the magnetic induction of the specimen. The process is repeated with a series of different currents, giving a series of points on the magnetization curve. When a cyclic process is to be investigated, the procedure is different. The current is first adjusted by means of R to a value which determines the extremity of the cycle; it is reversed several times to find the corresponding induction (as in the former case). Then it is suddenly reduced by opening the short-circuit key S, and thereby inserting the resistance $R_2$, the key K having been previously put over to the appropriate side. This allows any point between *a* and *b* in the curve of *Fig. 2* to be found, $R_2$ being adjusted beforehand to a suitable value. The swing of the galvanometer measures the step by which the magnetism is reduced in passing from *a* (the extremity of the cycle) to the point in question. To continue the process, the key K is switched over to the other side, and then, while S is open, is switched back, thereby changing the current from its full value to a value reversed in sign and diminished in amount by an amount adjusted by varying $R_2$ beforehand. This allows points to be found lying anywhere between *b* and *c* of *Fig. 2*, and therefore completes the determination of the curve. As the return curve is a copy of the first, no separate determination of it is required. The process is at the best somewhat laborious, but with a little experience and practice in the adjustment of the resistance $R_2$ to give suitable points in the curve, the observations may be completed rapidly enough, though the reduction of them and the drawing of the curve are operations which necessarily take a considerable time. An example of a set of magnetic cycles



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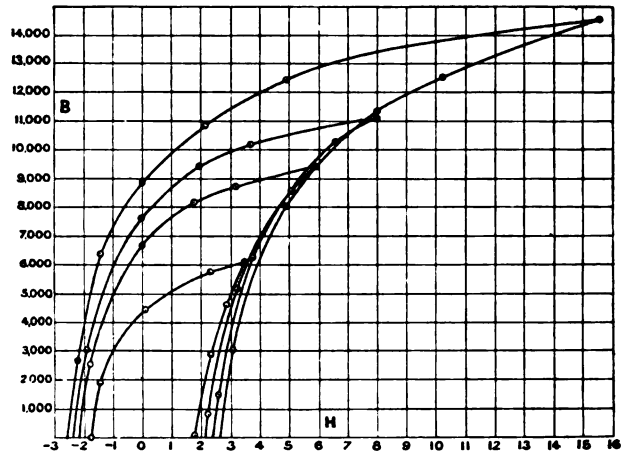
determined in this way for a ring of cast steel is given in *Fig. 5*, where half the cyclic curve for each is drawn. The points of observation are marked, and it will be noticed that they give well-defined smooth curves.

In preparing rings to be tested by the ballastic method, it is desirable to make the dimensions such that there will be no large variation in the magnetizing force between the inside and the outside of each section. For this reason the width of the section measured radially should be small compared with the mean radius. In testing sheet iron, rings turned or stamped out of the sheet 3 inches to 4 inches in external diameter and about $\frac{1}{4}$ inch in radial width will serve, several of these being piled on one another to

*Fig. 5.*




make up sufficient cross-section. Another construction for rings of sheet iron is to take a long strip and bend it into a ring of two or more turns, with the ends just overlapping. It is then essential to re-anneal the ring, for the bending hardens the metal sufficiently to make a large difference in its permeability and hysteresis. In general the flat stamped or turned ring is a fairer sample, not only because it allows the metal to be tested in its original state as regards annealing, but also because it gives the average quality of the sheet apart from any variation that may exist along and across the direction of rolling. The Author finds that a ring made by bending a long strip which has been cut in the direction of rolling, when annealed after this bending, shows considerably more permeability and somewhat less hysteresis than

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one which is formed of annular stampings or turned annular pieces of the same metal, also annealed.

*Gap Methods.*—Several other methods of finding B may be passed with much briefer mention. Some of these depend on the presence of a narrow gap in the magnetic circuit, the number of lines of force crossing the gap being measured. The gap may be either in the sample itself or in a yoke-piece used to complete the magnetic circuit. In the Author's "magnetic curve tracer" B is measured by the device of stretching in the gap a wire conveying a constant current; the development of magnetism across the gap causes the wire to sag by pushing it across the lines of force. Its deflection is proportional to the magnetic induction across the gap. In Dr. Koepsel's apparatus the gap takes the form of a cylindrical pole in which a small coil is pivoted like the coil of a d'Arsonval galvanometer; a constant current passes through the coil and its deflection measures the induction.[1] Substantially similar apparatus has also been suggested by Mr. A. E. Kenelly and Mr. L. T. Robinson.[2] In an apparatus[3] made by Messrs. Hartmann and Braun a spiral of bismuth wire is inserted in the gap and serves to measure the induction by means of the change of resistance which bismuth is found to undergo when placed in a magnetic field. In regard to all instruments using a gap in the magnetic circuit, the general observation may be made that K, the correction for the gap to be applied in calculating the true magnetizing force by the formula $H = H' - K$, is generally large. In other words, the true magnetizing force H is found as the difference between two relatively large quantities. This makes any error in determining K produce a much more than proportional error in the resulting value of H. The same objection can scarcely be said to hold in the use of ellipsoids, for K can then be determined with any degree of accuracy by calculation from the measured dimensions of the ellipsoid.

*Magnetometer Method.*—When ellipsoids or long rods are used, the magnetism may be measured by means of a magnetometer formed by suspending a magnetic needle at a point outside the piece under test. This method, which is of course inapplicable to rings or to bars closed by a yoke, will be found described in many text-books,[4] and is so little in practical use that it need not be further referred to here.

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[1] The *Electrician*, vol. xxxiii. p. 274.
[2] The *Electrical World*, New York, vol. xxiii. p. 236.
[3] *Industries*, vol. xiv. p. 450.
[4] "Magnetic Induction in Iron and other Metals," p. 37.



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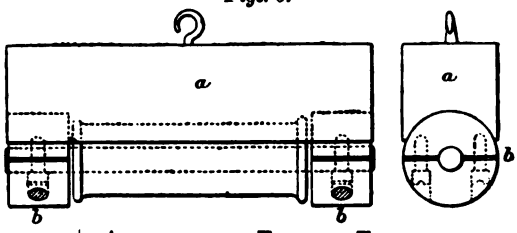
*Traction Methods.*—Another method of finding B is based on the fact that when magnetic induction crosses a joint between two surfaces, the surfaces can only be separated by applying a pull which depends on the intensity of the induction. The value of this "tractive force" is $\frac{B^2}{8\pi}$ in dynes. Thus Mr. Shelford Bidwell has measured the induction in a divided ring by observing the force required to pull the halves of the ring asunder, the magnetizing coil being also divided so that its halves should part company along with those of the ring. Simple forms of traction "permeameter" have been devised by Professor Silvanus P. Thompson[1] and Mr. Gisbert Kapp,[2] in both of which the specimen is a bar within a yoke. Both of these require that one end of the specimen shall be carefully faced to form the surface at which the magnetic attraction to be measured occurs. To escape this necessity of facing the joint as well as to meet some other objections, the Author has designed

*Figs. 6.*




APPARATUS FOR TRACTION TESTS.

another simple form of traction apparatus in which the joint is between two surfaces in the yoke. He makes the yoke in three pieces, *Figs. 6*, one of which (*a*) is pulled away simultaneously from the other two (*b b*); *b b* are short cylinders into which the ends of the test-piece fit, and *a* is a piece joining them turned on its inner surface to the same radius as the outsides of *b b*. The bar itself keeps *b b* in alignment, and *a* then lies against both. To standardize the instrument, the relation between the pull required to remove *a* and the induction in the bar is determined experimentally by testing a bar furnished with an induction coil which allows ballistic measurements of B to be made. In all apparatus of this type it is important to remember that the presence of the joint affects the true value of H by rendering a correction K

[1] Journal of the Society of Arts, vol. xxxviii. p. 885.

[2] "On Methods of Testing the Magnetic Qualities of Iron," Journal of the Institution of Electrical Engineers, vol. xxiii. p. 199.

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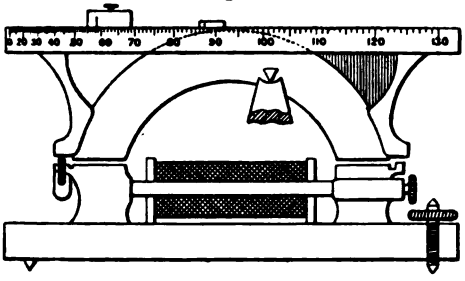
necessary (in addition to the correction which is required on account of the yoke); and further, that unless the surfaces at the joint fit truly, not only is the amount of this correction uncertain, but the distribution of the induction is irregular and the pull consequently greater than a uniform distribution of the same mean intensity would produce. Traction methods are scarcely likely to yield satisfactory results unless particular care be taken not only in the construction but in the use of the apparatus; and when a skilled observer is available they offer little, if any, advantage over the ballistic process, while they are, for the most part, subject to some uncertainty as to the true value of the magnetizing force.

The most perfectly developed apparatus of the traction type is the magnetic balance of Dr. H. du Bois, *Fig. 7*. Here the pull is measured not between the faces in contact at a joint, but between

*Fig. 7.*



DU BOIS MAGNETIC BALANCE.

portions of the yoke separated by a narrow gap of definite width. The bar is inserted between two terminal blocks and the magnetic circuit is completed by a rocking yoke supported on a knife edge and provided with a scale and travelling weights. The test is made by moving the weight until the rocking piece is pulled away from a stop on the left-hand side which determines the width of the gap. Dr. du Bois provides, in the form of a curve, the necessary correction to reduce H′ to H for any observed value of the magnetism. The details of this instrument are worked out with much skill, and in good hands it will no doubt yield satisfactory results.[1]

*Use of the Bar and Yoke. Determination of the Correction K.*—The bar and yoke, as a device for securing approximate endlessness, has been extensively used as a substitute for rings, both in ballistic

[1] For a fuller description see the *Electrician*, vol. xxix. p. 448.

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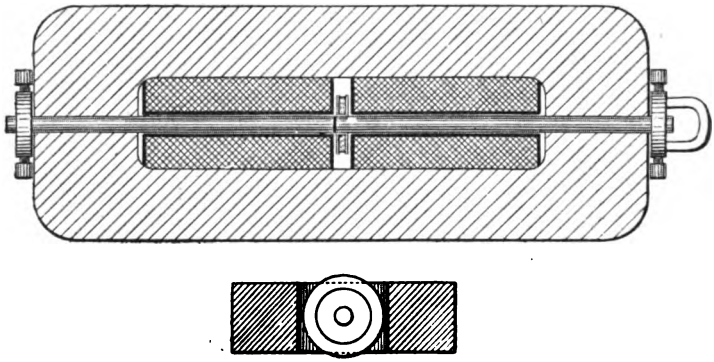
and traction tests. The chief advantages of the bar in a yoke over the ring are that the bar is a form of specimen somewhat easier to prepare, and especially that it does not require that each specimen should have its own magnetizing coil wound upon it as is necessarily the case in testing a ring. The bar generally takes the form of a turned rod, and has only to be slipped into a bobbin on which the coil is ready wound. In Dr. Hopkinson's original use of the yoke the bar was in two pieces abutting in the middle, *Figs. 8*, and the induction coil was wound on a small bobbin which was made to fly out by a spring when one of the pieces of the bar was drawn back. This allowed the induction in the bar to be measured at any time after the magnetizing current had been passed through any series of values, and had been brought into

*Figs. 8.*



HOPKINSON BAR AND YOKE.

any desired steady state. It therefore had the advantage of avoiding error arising from the sluggishness with which the yoke takes up its magnetism after any alteration in the magnetizing current; but this advantage was secured at the cost of introducing a joint, with consequent increase in the difference between the true magnetizing force and the nominal magnetizing force H′. Apart from the influence of the joint the yoke itself renders some correction of H′ necessary, in strictness, if H′ is reckoned as $\frac{0{\cdot}4\,\pi\,C\,N}{L}$, where L is the clear length of the bar within the yoke. Moreover the correction is not strictly the same for all bars (even for one and the same value of B), since part of it is due to the fact that the virtual length of the bar is greater than the clear length, and the correction is consequently greater, at any

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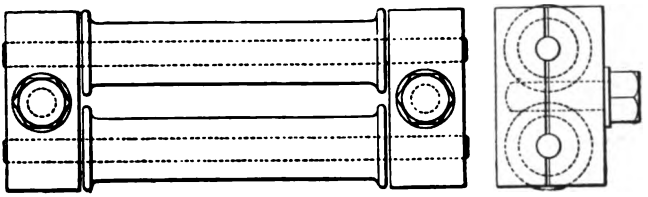
given induction, the less permeable the bar. Of the whole number of ampere-turns in the magnetizing coil some are used in overcoming the magnetic resistance of the yoke, and some in overcoming the resistance which the induction meets with in getting from the clear part of the bar into the yoke; and only the remainder are effective in overcoming the magnetic resistance of the bar itself, reckoned on the clear length L. However permeable the quality of the yoke, and however large its section, the second term in the correction remains to be applied if the true value of the magnetizing force is to be determined.

It is clearly desirable to make the magnetic resistance of the yoke small, and still more desirable to arrange it so that the correction K can be experimentally found. These conditions are satisfied by a form of yoke used by the Author and shown in *Figs. 9.* There the specimen consists of two bars, magnetized in

*Figs. 9.*



opposite directions, and united by short yokes at each end. Each of the two yokes is a small block of soft iron with holes bored to fit the bars, and split in the diametral plane to allow the bars to be tightly clasped by means of a screw-bolt. By loosening this screw, the yokes may be slipped along the bars so as to enclose between them any portion of the whole length. To find the amount of the correction, or $H - H'$, it is only necessary to take two sets of observations, one with the yokes extended as far as the bars allow, and another with the clear length reduced to one-half. If $H'$ be the value of $\frac{0{\cdot}4\pi C N}{L}$ in the former case, and $H''$ its value in the latter case for the same induction B, it is easy to show that the correction applicable to $H''$ is just twice as great as that applicable to $H'$, and hence that $H'' - H'$ is the value of the correction K to be subtracted from $H'$ in order to find the true magnetizing force H.[1]

[1] To prove this, let $N_1 L_1$ denote the number of turns and the clear length in the first case, and $N_2 L_2$ denote them in the second case. Let $C_1$ and $C_2$ be the

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In a particular application of this method the Author has used bars ¼ inch in diameter and barely 4 inches long. The yokes are set so that the clear length between them is 6·28 (or 2 $\pi$) centimetres and the magnetizing coils have each one hundred turns. Hence H′ is found by multiplying the number of amperes by twenty. In the second part of the experiment, where the clear length is reduced to one-half, magnetizing coils of fifty turns are used, and hence H″ is also found by multiplying the number of amperes by twenty.

*Fig. 10.*

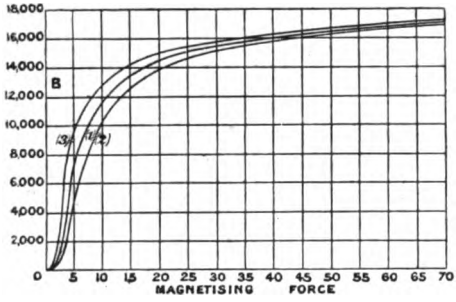


*Fig. 10* illustrates a test carried out in this way of a pair of rods of Low Moor iron. The curve (1) shows H′ in relation to B, and curve (2) shows H″ in relation to B. When a third curve (3) is drawn by setting back points from the first through a distance equal to H″ − H′, it gives the relation of B to the

---

respective currents in amperes required to produce the same value of B. Then, in the first case,

$$0{\cdot}4\,\pi\,C_1\,N_1 = H\,L_1 + \epsilon,$$

where $\epsilon$ is that part of the "magneto-motive force" which is used up in overcoming the magnetic resistance of the yoke and of the sunk ends of the bars. In the second case, when B has the same value as before,

$$0{\cdot}4\,\pi\,C_2\,N_2 = H\,L_2 + \epsilon.$$

Here H, the true magnetizing force, is the same as before, since B is the same, and for the same reason $\epsilon$ is also unchanged.

Hence $$H' = H + \frac{\epsilon}{L_1},$$

and $$H'' = H + \frac{\epsilon}{L_2},$$

from which $$H'' - H' = \frac{\epsilon}{L_2} - \frac{\epsilon}{L_1}$$

If we make $$L_2 = \tfrac{1}{2}\,L_1,$$

$$H'' - H' = \frac{2\,\epsilon}{L_1} - \frac{\epsilon}{L_1} = \frac{\epsilon}{L_1}.$$

This is the correction denoted in the text by $K_1$, which has to be subtracted from H′ to find H. The correction is consequently found by taking the excess of H″ over H′. See the graphic construction given in *Figs. 10* and *11*.

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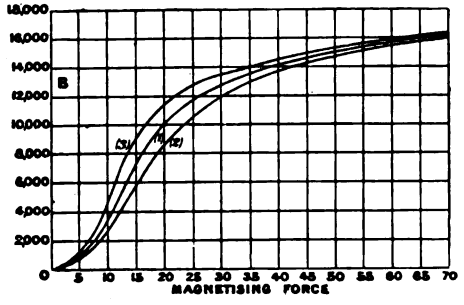
true magnetizing force H. *Fig. 11* gives in the same way the results for a pair of mild-steel rods of the same dimensions as the Low Moor rods of *Fig. 9*, and tested with the same yoke pieces. It will be noticed that the correction K is greater for the steel rods in consequence of the greater magnetic resistance of the sunk ends.[1] The correction K is considerable in both cases, and might advantageously be reduced by using longer rods.

*The Magnetic Bridge.*—From the point of view of workshop testing, each of the methods which have been referred to leaves a good deal to be desired, either in respect of simplicity or in respect of accuracy. In the hope of combining these qualities the Author has devised a new apparatus for testing the permeability of iron and steel, which is based on the principle of reducing the test to a comparison of the rod to be examined with a standard rod, the magnetic curve of which has been already determined. This makes the operation of testing comparatively easy, the more difficult part having been done beforehand by the instrument-maker in his test of the standard rod. The process resembles the measurement of resistance in the Wheatstone bridge by comparison with standard coils, and from its analogy to this the Author suggests that the new instrument might be called a magnetic bridge, or, more particularly, a permeability bridge. The rod to be tested is turned to the same dimensions as the standard rod, and the two are made to form one magnetic circuit by short yokes joining their ends. The arrangement is illustrated

*Fig. 11.*




[1] From these curves the total correction may be apportioned into its two constituents, that due to the sunk ends or $K_s$, and that due to the yoke proper or $K_y$, the latter being the same for the steel rods as for the iron rods. Thus with the condition of B = 10,000, for the iron rods H′ = 7·6, H = 5·5, K = 2·1, and for the steel rods H′ = 19·8, H = 16·3, K = 3·5. Then, since $K_s$ for the steel is $\frac{16\cdot3}{5\cdot5}$ times $K_s$ for the iron (say 3 times)—

$$K_y + K_s = 2\cdot1\,;\ K_y + 3K_s = 3\cdot5,$$

from which $K_y = 1\cdot4$, and $K_s$ for the iron = 0·7. In other words, with the Low Moor rods, at B = 10,000, one-third of the whole correction may be taken as due to the sunk ends, and the remaining two-thirds to the yoke-pieces themselves.

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diagramatically in *Fig. 12.* The bars are shown at $a\,a'$ and the yokes are $b\,b'$. So long as the magnetic induction B is the same in both bars there will be no difference of magnetic potential between the yokes. In that case, if the yokes are connected by a third magnetic conductor $c$ (say a soft iron bar) there will be no magnetic induction in $c$. The absence of magnetic induction in $c$ may be tested most conveniently by making a gap in it and inserting there a compass-needle to serve as detector. If $a$ and $a'$ are of the same magnetic quality it will require the same number of ampere-turns on both to prevent magnetic induction in $c$ when the rods are magnetized. But if $a'$ is less permeable than the standard rod $a$, it will require a larger number of ampere-turns than $a$. The test consists in varying the number of ampere-turns on one of the rods, while the number on the other is kept constant, until on reversal of the current no reversal of induction is seen in $c$. In practice this is effected by varying the number of turns in the magnetizing coil of one rod, the same current serving for both coils. Then when a balance is obtained in the detector in $c$ the magnetizing forces on the two rods are proportional to the respective number of turns, while B is the same for both. Moreover B is known, since the relation of the magnetizing force to B in the standard rod has been determined beforehand.

*Fig. 12.*

*Figs. 13* and *14* show the instrument in detail. The yokes are in the form of iron rings $b\,b'$ held in place by three longitudinal brass rods $f\,f\,f$. The cross yoke is formed of iron pieces, $g\,g$, which are carried up to bring the detector far enough from the bars to avoid the direct effects on it of the magnetizing current in the coils. The detector $h$ has a sensitising and directing magnet, $k$, adjustable on a brass rod below it. The standard bar $a$ has a coil of one hundred turns, and, as its clear length is 12·56 centimetres, the corresponding magnetizing force (H′) is 10 C.G.S. units per ampere of current. The bar under test, $a'$, has a coil which can be varied from one turn to three hundred and ten turns by means of the dial switches $d_1\,d_2\,d_3$, *Fig. 14.* Of these, $d_1$ adds in one turn for each step, $d_2$ adds ten turns per step, and $d_3$ one hundred turns. In each case the act of switching in more turns in the magnetizing coil cuts out equal resistances, and *vice versâ*, by means of contacts on the other half of each dial, with the effect that the current is not changed in varying the number of turns. The current is brought to any desired value by means of

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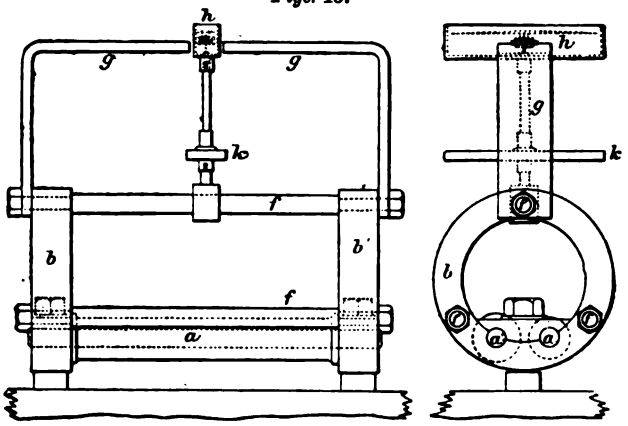
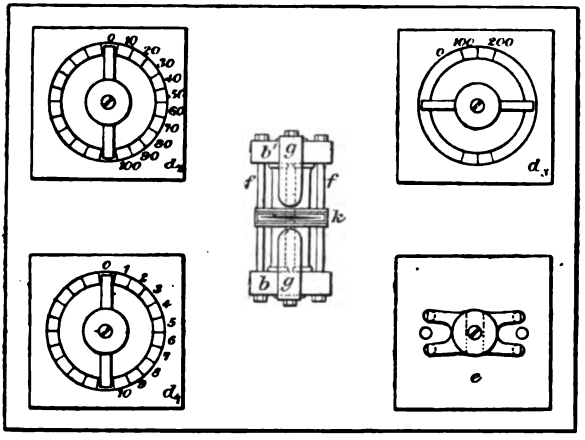
an outside resistance and is read on an ampere-gauge. It is then reversed repeatedly by means of the reversing key *e*, while the

*Figs. 13.*




*Figs. 14.*




PERMEABILITY BRIDGE.

dial switches are manipulated until the reversal does not cause any permanent displacement of the detector needle *h*.[1] The

[1] There may be, and generally are, momentary deflections of the needle due to differences in the time-rate at which the two bars take up their magnetism at each reversal of the current. In developing this instrument the Author at first endeavoured to test the condition of balance by using a simple form of ballistic detector, using a pair of differentially wound induction-coils on the two bars, or a single coil on the cross-yoke; but he found that it was difficult to get such readings owing to the circumstances just mentioned, and that the magneto-static method described in the text was much to be preferred.

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number of turns on the dials is then read off and gives the proportion to one hundred which the magnetizing force on the test-piece bears to the magnetizing force on the standard bar. The magnetizing force on the standard bar is known, being ten times the number of amperes. By referring to the data for the standard bar B is found. It is the same for both bars. Thus the relation of the magnetizing force to B in the test-bar is determined, which is the object of the test. By using a series of currents of graded strength as many points in the curve are found as may be wished. In practice, the detector is easily able to show a difference of 1 per cent. in the magnetizing forces required by the two bars.

What is found in this way is the ratio of H′ in the two bars. The value of K for the standard bar can be found and tabulated beforehand by the method already given; but so long as the test-bar is not excessively different in magnetic quality from the standard bar no important error is caused by taking the ratio of the true force H in the two bars to be the same as the ratio of H′ in the two.

It should be added that the general idea of comparing permeabilities in the two arms of a magnetic circuit is not new. The Eickemeyer Differential Magnetometer, as described by Mr. Steinmetz,[1] had a pair of yokes on which a magnetizing coil was wound. Between these, on one side, was placed the bar to be tested, while a bar of Norway iron was placed on the other side, and this was supplemented by "fractional standard pieces" of Norway iron until a detector set mid-way between the yokes showed a state of balance. Mr. Steinmetz points out the analogy of this arrangement to the Wheatstone bridge. In the Author's apparatus a balance is produced by varying the relative magnetizing forces instead of the relative sections of the two sides of the magnetic circuit, and the difference of magnetic potential between the yokes, due to any want of balance, is caused by the cross yoke-pieces to produce a concentrated effect on the detector instead of merely setting up magnetic leakage through the air.

### Direct Hysteresis Tests.

In judging of the suitability of iron for transformers, what is required is a knowledge of the energy lost in consequence of hysteresis, in carrying the iron through reversals of magnetism

[1] The *Electrical Engineer*, New York, vol. xi. (March, 1891) p. 353; also Transactions of the American Institute of Electrical Engineers, vol. ix. p. 3.

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between known limits, positive and negative, of the induction B. Various plans have been followed to measure this loss more directly than by the necessarily somewhat laboured process of determining the B–H curve for a cycle of reversals, and then finding the area enclosed within it. Thus one specimen of sheet iron has been compared with another by piling up strips of both to form the equal cores of two equal coils, then causing an alternating current to act in both coils, and observing by a thermometer the rise of temperature in each core after a given time. The heating effect here is complicated, being due not only to hysteresis but partly to the direct action of the current in the conducting wire of the coils, and partly to the production of eddy or Foucault currents in the iron. The direct heating by the current is insignificant when the core is arranged to form a closed magnetic circuit, and the Foucault effect is small, provided the plates are thin and the frequency of the alternations is not excessive. Under these conditions the comparison is essentially a comparison of hysteresis losses. But to have a fair comparison the limits of induction B must be the same in both cores, and this is best secured by using cores which do not form complete magnetic circuits, in order that the magnetic resistance of the iron itself may be no more than a small part of the whole. In the watt-meter method, the energy expended in causing magnetic reversal to occur is found by using a watt-meter to measure the work done by the alternating current of the magnetizing circuit. Here again the total loss is in question, including the two sources of loss just mentioned as well as the hysteresis. The most satisfactory form of core for this test is one built up of ring-shaped stampings, but this requires each specimen to be separately wound with its magnetizing coil. To avoid this necessity Mr. Kapp has used a composite magnetic circuit formed by an open horse-shoe made up of plates of a definite quality, with a straight bar to close it made up of rectangular strips of the iron to be tested.[1] In the watt-meter method the limiting positive and negative value of B are inferred from voltmeter readings on the magnetizing coil or on a secondary wound on the core under test, and an objection to the watt-meter method in any form is that this does not give the limiting value of B with any certainty, since the voltmeter readings depend, to some extent, on the particular function which expresses the rate of variation of B.[2] Indeed, however accurately the measurements of hysteresis loss under the

[1] Journal of the Institution of Electrical Engineers, vol. xxiii. p. 205.

[2] Philosophical Transactions of the Royal Society, vol. clxxxiv. p. 1024.

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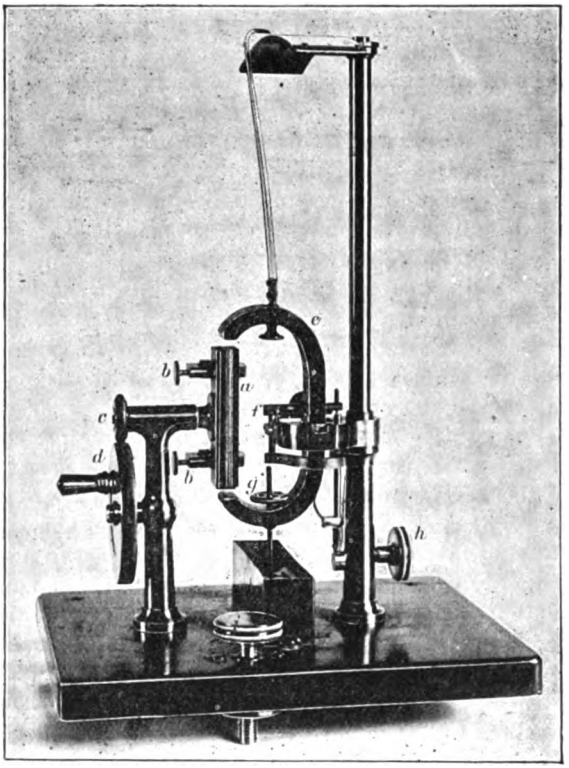
alternating current are carried out, their relation to B remains imperfectly established; and it is the object of the test to establish this relation.

In the Author's hysteresis tester for sheet-iron, a mechanical method is used for measuring the work done in producing magnetic reversals. The reversals are produced by causing the

*Fig. 15.*




HYSTERESIS TESTER.

sample to revolve in the gap between the pole of a widely open horse-shoe magnet, and the work is measured by observing the mechanical couple existing between the magnet and the revolving sample. The instrument is shown in *Fig. 15.*

The sample is prepared by cutting or stamping a number of strips from the iron sheet, 3 inches long and $\frac{5}{8}$ inch wide, and

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piling about half a dozen of them (the number used depending on the thickness) into a bundle, which is placed in a carrier *a*, covered with a vulcanite washer, and secured by clamps *b b*. The carrier is made to revolve by the friction-pulley *c* and hand-wheel *d*, and the magnet *e* causes the induction in the sample to be reversed at each half-revolution. The hysteresis gives rise to a mechanical moment between the sample and the magnet, which is measured by the device of supporting the magnet on a knife edge *f* in line with the axis of the carrier, and giving it a small amount of stability by the adjustable weight *g*. The magnet is therefore free to be deflected by this mechanical moment, and its deflection, which is observed by means of the pointer and scale above, serves to measure the work spent in overcoming hysteresis in each revolution of the carrier. The deflection is independent of the speed at which the carrier is turned (so long as that is not so high as to cause a supplementary deflection by air currents or Foucault currents), and hence no particular care has to be taken to turn the handle at a uniform rate. There is a vane working in oil below the magnet, which serves as a dash-pot, and the operator has merely to turn the handle just fast enough to make the impulses which are given at each half-revolution blend into a steady deflection. The deflection is observed first to one side and then to the other by reversing the rotation of the sample. The handle at *h* serves to lift the knife edge off its agate-bearing when the instrument is not in use, or when a sample is being inserted or removed.

A considerable air-space is left between the ends of the sample and the magnet-pole, with the result that the total fall of magnetic potential from pole to pole takes place almost wholly in the air-spaces, and consequently that such variations of permeability as are met with in different samples are almost wholly without influence upon the total induction through the iron. This is important, since in comparing the hysteresis of one specimen with another the induction should be the same for both. The induction used in testing is about 4,000 C.G.S. units. The Author found, however, that no exact adjustment of the section of the sample was necessary, and that in making up the bundle it is sufficient to take that number of strips which comes nearest in total weight to the weight of the standard sample.[1] In practice the testing is done by comparing the deflections given by the samples under examination with the deflections given by two standard samples, the hysteresis of which has been determined beforehand. The deflection is not

[1] Journal of the Institution of Electrical Engineers, vol. xxiv. pp. 403–405.

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simply proportional to the hysteresis, for it includes a small constant term, probably due, for the most part, to the fact that there is some hysteresis loss within the magnet itself when the sample is revolving, in consequence of changes in the distribution of its magnetism every time the sample passes the poles. The Author's experiments, made by observing the deflection given by a series of samples, for which the hysteresis had been determined in ballistic tests, show that the calibration curve is a straight line.[1] From this it follows that the deflections given by two standard samples are sufficient to allow any other specimen to have the absolute value of the hysteresis determined. The hysteresis of the standards is stated for B = 4,000, and the comparison of deflections therefore gives results applicable to that value of B. If it be desired to infer the hysteresis for any other induction, this is readily done by help of the following Table:

| Limits of Induction B. | Relative Amounts of Hysteresis. |
|---|---|
| 2,000 | 0·33 |
| 2,500 | 0·47 |
| 3,000 | 0·63 |
| 4,000 | 1·00 |
| 5,000 | 1·41 |
| 6,000 | 1·89 |
| 7,000 | 2·41 |
| 8,000 | 3·00 |

The advantages of this apparatus are not only that the test is a mechanical one, made quickly and without special skill on the part of the observer, but that the sample is expeditiously prepared and consumes no more than a few square inches of the iron sheet. The simplicity of the whole operation makes it practicable to test a number of samples from a single batch of plates or stampings, and hence to obtain a fair average for the quality of the batch. That this is desirable is obvious from the fact that wide differences in respect of hysteresis are found between one plate and another in the same batch, and even between different portions of the same plate.

## Results of Tests.

It remains to give a few representative results, both of permeability and of hysteresis tests. With one exception those which follow are tests made by the Author, and relate to the iron supplied

[1] Journal of the Institution of Electrical Engineers, vol. xxiv. p. 338.

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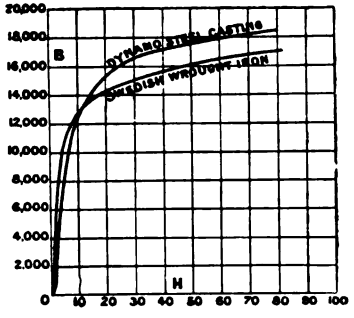
commercially for dynamo-magnets or for transformer or armature cores.

In the construction of dynamo magnets "steel" castings, or forgings from ingots produced by a "steel" process, have very largely taken the place of forgings from scrap- or puddled-iron. A characteristic of much of the metal now used is its remarkable chemical purity. In some of the steel castings now used for dynamo magnets it appears that of the total foreign matter, including carbon, manganese and silicon, is no more than 0·3 per cent. of the whole, the remaining 99·7 per cent. being pure iron. It has long been recognised that the absence of impurities in the iron conduces in a general way to permeability, Swedish iron, for example, having a high reputation in this respect. But the magnetic effect produced by varying any one of the foreign substances when present in small quantity is not even now distinctly known. It would evidently be a matter of considerable interest and practical consequence to ascertain how far the presence of, say, manganese or silicon, might be permitted without serious detriment to the magnetic quality of the material; but if such an inquiry has been carried out the results have not, so far as the Author knows, been made public.

*Fig. 16.*




In comparing the metal now supplied for dynamo-magnets with such iron as Swedish or Low Moor forgings, a distinction is to be noticed which *Fig. 16* will serve to make clear. Of the two curves drawn there to show the relation of the induction B to the magnetizing force H, one is a representative example of Swedish wrought iron, and the other is a favourable example of unforged dynamo-steel cast by an English maker. A characteristic curve for annealed Low Moor iron would almost coincide with the curve given here for Swedish iron. Either of these wrought metals is more permeable than the casting when exposed to low magnetizing forces, but less permeable when the force exceeds about 10 C.G.S. units. In the upper region of the curve each magnetizing force produces a decidedly higher induction in the casting than in the soft wrought metal. From the dynamo-makers' point of view a magnetic quality such as that shown by the casting is to be



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preferred, for the magnetization of dynamo magnets lies in the upper region of the curve, and the permeability under low forces is a matter of no account. Between the best specimens of unforged steel castings and the best specimens of forged ingot metal there is, in the Author's experience, very little to choose. The general effect of forging is to give higher permeability in the early stages of the curve, but in the later, and (so far as regards dynamo magnets) the important stage, the curves for forged and unforged metal are found in the best cases to lie very close, almost coinciding with or just crossing each other when the magnetization is pushed to high values. In some cases, it may be added, steel castings have high permeability even under weak magnetizing forces.

In the following Table, numerical results are given for six samples of iron or steel, all tested in the form of solid turned

PERMEABILITY OF FORGINGS AND CASTINGS.

| Magnetizing Force H. | Magnetic Induction B. | | | | | |
|---|---|---|---|---|---|---|
| | I. | II. | III. | IV. | V. | VI. |
| 5 | 12,700 | 10,900 | 12,300 | 4,700 | 9,600 | 10,900 |
| 10 | 14,980 | 13,120 | 14,920 | 12,250 | 13,050 | 13,320 |
| 15 | 15,800 | 14,010 | 15,800 | 14,000 | 14,600 | 14,350 |
| 20 | 16,300 | 14,580 | 16,280 | 15,050 | 15,310 | 14,950 |
| 30 | 16,950 | 15,280 | 16,810 | 16,200 | 16,000 | 15,660 |
| 40 | 17,350 | 15,760 | 17,190 | 16,800 | 16,510 | 16,150 |
| 50 | .. | 16,060 | 17,500 | 17,140 | 16,900 | 16,480 |
| 60 | .. | 16,340 | 17,750 | 17,450 | 17,180 | 16,780 |
| 70 | .. | 16,580 | 17,970 | 17,750 | 17,400 | 17,000 |
| 80 | .. | 16,800 | 18,180 | 18,040 | 17,620 | 17,200 |
| 90 | .. | 17,000 | 18,390 | 18,230 | 17,830 | 17,400 |
| 100 | .. | 17,200 | 18,600 | 18,420 | 18,030 | 17,600 |

rings, using the ballistic method. No. I is quoted from data given in a Paper by Messrs. Lydall and Pocklington[1] as a test of exceptionally pure iron supplied for the purpose of experiment by Colonel Dyer of the Elswick Works. The substances other than iron in the sample were stated to be: carbon, trace; silicon, trace; phosphorus, none; sulphur, 0·013; manganese, 0·1. The other five are samples of commercial iron tested by the present writer. No. II is a sample of Low Moor bar, forged into a ring, annealed and turned. No. III is a steel forging furnished by Mr. R. Jenkins as a sample of forged ingot-metal for dynamo

[1] Proceedings of the Royal Society, vol. ii. p. 228.

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magnets.[1] No. IV is a steel casting for dynamo magnets, unforged, made by Messrs. Edgar Allen & Co. by a special pneumatic process under the patents of Mr. A. Tropenas.[1] No. V is also an unforged steel casting for dynamo magnets, made by Messrs. Samuel Osborn & Co.[1] by the Siemens process. No. VI is also an unforged steel casting for dynamo magnets, made by Messrs. Fried. Krupp, of Essen.[1]

Of the steel castings No. VI is remarkable for its permeability under weak magnetizing forces. This characteristic is better shown in the following Table, which gives the magnetizing forces required to produce certain stated amounts of induction, and also the corresponding values of the permeability $\mu$. This Table relates to specimens I, III, and VI, all of which have high permeability in the early stages of the magnetizing process.

PERMEABILITY UNDER WEAK MAGNETIZING FORCES.

| Magnetic Induction B. | I. Pure Iron. | | III. Steel Forging. | | VI. Steel Casting. | |
|---|---|---|---|---|---|---|
| | H. | $\mu$ | H. | $\mu$ | H. | $\mu$ |
| 2,000 | 0·90 | 2,220 | 1·38 | 1,450 | 1·18 | 1,690 |
| 4,000 | 1·40 | 2,850 | 1·91 | 2,090 | 1·66 | 2,410 |
| 6,000 | 1·85 | 3,240 | 2·38 | 2,520 | 2·15 | 2,790 |
| 8,000 | 2·30 | 3,480 | 2·92 | 2,740 | 2·83 | 2,830 |
| 10,000 | 3·10 | 3,220 | 3·62 | 2,760 | 4·05 | 2,470 |
| 12,000 | 4·40 | 2,760 | 4·80 | 2,500 | 6·65 | 1,810 |

In further illustration of the properties of steel castings for dynamo magnets, the following Table is useful as showing how

TESTS OF OTHER SAMPLES OF CASTINGS PRODUCED BY THE SAME PROCESS AS NO. IV.

| Magnetizing Force H. | Magnetic Induction B. | | | |
|---|---|---|---|---|
| | IV*a*. | IV*b*. | IV*c*. | IV*d*. |
| 20 | 15,200 | 15,200 | 15,450 | 15,500 |
| 30 | 16,000 | 16,050 | 16,200 | 16,150 |
| 40 | 16,600 | 16,450 | 16,700 | 16,600 |
| 50 | 17,000 | 16,850 | 17,100 | 17,000 |
| 60 | 17,300 | 17,200 | 17,450 | 17,300 |
| 70 | 17,600 | 17,500 | 17,700 | 17,600 |

[1] The Author is indebted to these and other gentlemen for permission to publish the results of tests made in the course of examining samples submitted to him for report. For assistance in carrying out other tests specially for this Paper he is indebted to two of his pupils, Messrs. Roget and Werner.



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nearly alike in their behaviour under strong forces different castings produced by the same process may be. The Table gives the results of tests of four other samples by the same makers as No. IV already quoted. Some of these castings were made in 1894, others in 1896. These tests are further interesting as having been made with the Author's new magnetic bridge, which is particularly well adapted for exhibiting small differences between one sample and another.

These may be taken as favourable examples of the permeability of iron in bulk, whether forged or cast. The following tests relate

PERMEABILITY TESTS OF TRANSFORMER-PLATE AND WIRE.

| Magnetic Induction B. | VII. Transformer-Plate of Swedish Iron. | | VIII. Transformer-Plate of Scrap-Iron. | | IX. Transformer-Plate of Steel. | | X. Transformer-Wire. | |
|---|---|---|---|---|---|---|---|---|
| | H. | μ | H. | μ | H. | μ | H. | μ |
| 1,000 | 0·81 | 1,230 | 1·08 | 920 | 0·68 | 1,470 | 1·71 | 590 |
| 2,000 | 1·05 | 1,900 | 1·46 | 1,370 | 0·90 | 2,230 | 2·10 | 950 |
| 3,000 | 1·29 | 2,320 | 1·77 | 1,690 | 1·04 | 2,880 | 2·30 | 1,300 |
| 4,000 | 1·54 | 2,600 | 2·10 | 1,900 | 1·19 | 3,360 | 2·50 | 1,600 |
| 5,000 | 1·82 | 2,750 | 2·53 | 1,980 | 1·38 | 3,620 | 2·70 | 1,850 |
| 6,000 | 2·14 | 2,800 | 3·04 | 1,970 | 1·59 | 3,770 | 2·92 | 2,070 |
| 7,000 | 2·54 | 2,760 | 3·62 | 1,930 | 1·89 | 3,700 | 3·16 | 2,210 |
| 8,000 | 3·09 | 2,590 | 4·37 | 1,830 | 2·25 | 3,600 | 3·43 | 2,330 |
| 9,000 | 3·77 | 2,390 | 5·3 | 1,700 | 2·72 | 3,310 | 3·77 | 2,390 |
| 10,000 | 4·6 | 2,170 | 6·5 | 1,540 | 3·33 | 3,000 | 4·17 | 2,400 |
| 11,000 | 5·7 | 1,930 | 7·9 | 1,390 | 4·15 | 2,650 | 4·70 | 2,340 |
| 12,000 | 7·0 | 1,710 | 9·8 | 1,220 | 5·40 | 2,220 | 5·45 | 2,200 |
| 13,000 | 8·5 | 1,530 | 11·9 | 1,190 | 7·1 | 1,830 | 6·5 | 2,000 |
| 14,000 | 11·0 | 1,270 | 15·0 | 930 | 10·0 | 1,400 | 8·4 | 1,670 |
| 15,000 | 15·1 | 990 | 19·5 | 770 | .. | .. | 11·9 | 1,260 |
| 16,000 | 21·4 | 750 | 27·5 | 580 | .. | .. | 21·0 | 760 |

to the permeability of rolled plate, annealed after rolling, such as is used in transformers and dynamo armatures, and also of wire. They, too, are favourable cases, and, when compared with the foregoing, suggest that commercial iron is improved magnetically —so far as regards permeability under low magnetizing forces—in much the same way that it is improved mechanically, by the "work" put into it in the rolling-mill or the draw-plate. No. VII is a recent specimen of transformer-plate, 0·301 millimetre thick, rolled from Swedish iron by Messrs. Sankey of Bilston. No. VIII is a specimen of specially thin transformer-plate rolled from scrap-iron. No. IX is a specimen of transformer-plate rolled from ingot-steel. No. X is a specimen of the wire which was used by Mr. Swinburne some years ago to form the core of his "hedgehog" transformers. Its diameter was 0·602 millimetre. All these

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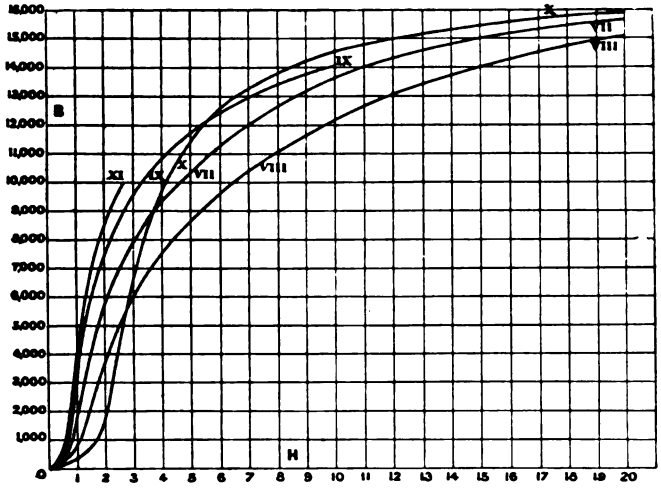
were tested in the form of rings, by the ballistic method, the rings of sheet metal being stamped or turned in the flat. The wire ring, No. X, was coiled and annealed after coiling.

Curves for these specimens are given in *Fig. 17*. It will be remarked that specimen X differs from the others in being less permeable at very low magnetizing forces; a little later, however, its curve rises very rapidly with the result that the maximum of permeability is high, and in the upper ranges of the curve this sample excels the others.

In the same *Fig.* another curve is shown (No. XI), which is

*Fig. 17.*




interesting as exhibiting the greatest permeability under low magnetizing forces which the Author has found in any specimen he has hitherto tested. This piece was a strip of Messrs. Sankey's

PERMEABILITY TEST OF SWEDISH TRANSFORMER-IRON NO. XI.

| B. | H. | $\mu$ | B. | H. | $\mu$ |
|---|---|---|---|---|---|
| 1,000 | 0·62 | 1,610 | 6,000 | 1·36 | 4,410 |
| 2,000 | 0·78 | 2,560 | 7,000 | 1·57 | 4,450 |
| 3,000 | 0·90 | 3,340 | 8,000 | 1·85 | 4,330 |
| 4,000 | 1·03 | 3,880 | 9,000 | 2·20 | 4,090 |
| 5,000 | 1·18 | 4,230 | 10,000 | 2·64 | 3,790 |

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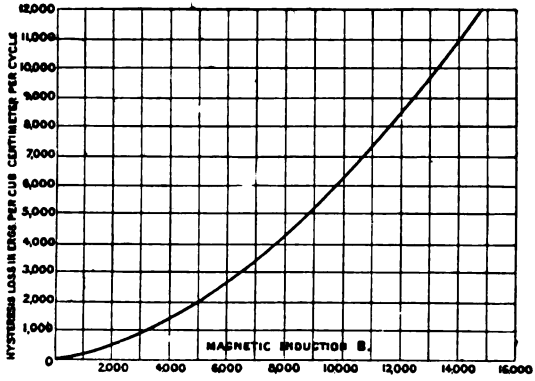
transformer-plate 0·33 millimetre thick rolled from Swedish iron; the strip was coiled into a ring of large diameter, and was re-annealed after coiling. It was of a different batch of plates from No. VII, but apart from this the difference in the mode of forming the ring is probably partly responsible for the higher permeability found in No. XI, for the reason already indicated. It will be noticed that the permeability is remarkably high. Reference will be made again to these samples in noticing the results of hysteresis tests.

*Hysteresis Tests.*—Hysteresis tests of dynamo-magnet steel are of little interest. The following results for the sample numbered IV above may, however, be quoted, as it does not appear that data of this kind for a steel casting have hitherto been published. In this

*Fig. 18.*




and in other cases to be quoted below, the ring was taken through a series of magnetic cycles, and the areas enclosed by the cyclic B–H curves were measured to find $\frac{1}{4\pi}\int H\,dB$, which is the work spent per cycle per cubic centimetre in C.G.S. units or ergs. *Fig. 5*, which has already been mentioned as an illustration of the method, shows the form of the cycles for ring No. IV. The measured areas, expressed in ergs, are represented in relation to the maximum B for each cycle in the curve of *Fig. 18*, and from this curve the numerical value of the hysteresis loss for any induction is found. Instead of expressing the loss in ergs per cubic centimetre per cycle, it is often, for convenience in transformer work, expressed in watts per lb. of iron, assuming the cycle to be gone through with a frequency of 100 per second. Taking the

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specific gravity of the iron to be 7·7, the factor for reducing the loss in ergs per cubic centimetre to watts per lb., with a frequency of 100 cycle per second, is 0·000589. In the Tables below both methods of stating the loss are used.

HYSTERESIS OF DYNAMO-MAGNET STEEL.

| Limits of Induction B. | In Ergs per Cubic Centimetre per Cycle. | In Watts per Lb. at a Frequency of 100. | Limits of Induction B. | In Ergs per Cubic Centimetre per Cycle. | In Watts per Lb. at a Frequency of 100. |
|---|---|---|---|---|---|
| 2,000 | 550 | 0·32 | 10,000 | 6,280 | 3·70 |
| 3,000 | 970 | 0·57 | 11,000 | 7,350 | 4·33 |
| 4,000 | 1,440 | 0·85 | 12,000 | 8,500 | 5·01 |
| 5,000 | 2,030 | 1·20 | 13,000 | 9,680 | 5·7 |
| 6,000 | 2,680 | 1·58 | 14,000 | 11,000 | 6·5 |
| 7,000 | 3,460 | 2·04 | 15,000 | 12,400 | 7·3 |
| 8,000 | 4,330 | 2·55 | 16,000 | 13,900 | 8·2 |
| 9,000 | 5,250 | 3·09 | | | |

Turning now to transformer metal, it will be seen that in favourable cases the hysteresis is considerably lower, just as the permeability under weak magnetizing force is higher. The following Table gives the hysteresis for the samples numbered VII to X above.

HYSTERESIS LOSS IN TRANSFORMER-IRON.

| Limits of Induction B. | Ergs per Cubic Centimetre per Cycle. | | | | Watts per Lb. at a Frequency of 100. | | | |
|---|---|---|---|---|---|---|---|---|
| | VII. | VIII. | IX. | X. | VII. | VIII. | IX. | X. |
| 2,000 | 240 | 400 | 215 | 600 | 0·141 | 0·236 | 0·127 | 0·356 |
| 3,000 | 520 | 790 | 430 | 1,150 | 0·306 | 0·465 | 0·253 | 0·630 |
| 4,000 | 830 | 1,220 | 700 | 1,780 | 0·490 | 0·720 | 0·410 | 1·050 |
| 5,000 | 1,190 | 1,710 | 1,000 | 2,640 | 0·700 | 1·010 | 0·590 | 1·550 |
| 6,000 | 1,600 | 2,260 | 1,350 | 3,360 | 0·940 | 1·330 | 0·790 | 1·980 |
| 7,000 | 2,020 | 2,940 | 1,730 | 4,300 | 1·200 | 1·730 | 1·020 | 2·530 |
| 8,000 | 2,510 | 3,710 | 2,150 | 5,300 | 1·480 | 2·180 | 1·270 | 3·120 |
| 9,000 | 3,050 | 4,560 | 2,620 | 6,380 | 1·800 | 2·680 | 1·540 | 3·750 |

These figures illustrate forcibly the contrast between good modern transformer metal and the iron which a few years ago

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was accepted as suitable. Favourable as the results in Nos. VII and IX are, they are excelled by those found in testing sample No. XI, the figures for which are worth quoting separately:—

HYSTERESIS LOSS IN STRIP OF TRANSFORMER-PLATE ROLLED FROM SWEDISH IRON (No. XI).

| Limits of Induction B. | Ergs per Cubic Centimetre per Cycle. | Watts per l.b. at a Frequency of 100. |
|---|---|---|
| 2,000 | 220 | 0·129 |
| 3,000 | 410 | 0·242 |
| 4,000 | 640 | 0·376 |
| 5,000 | 910 | 0·535 |
| 6,000 | 1,200 | 0·710 |
| 7,000 | 1,520 | 0·890 |
| 8,000 | 1,900 | 1·120 |
| 9,000 | 2,310 | 1·360 |

At B = 2,500, which is sometimes taken as a standard condition, the hysteresis loss in this sample is 0·185 watt per lb. at a frequency of 100. In samples No. VII the loss is 0·224 watt and in No. IX 0·19 watt at this value of B.

Mr. Mordey, in his remarks on a Paper by Mr. Kapp,[1] mentions that the Brush Company use transformer iron made to a specification which allows that with an induction of 2,500 and a frequency of 100 the loss may be 0·38 watt per lb. In the best of the samples cited here the loss is reduced to one-half of this amount.

The Author has had occasion to test a large number of pieces of transformer plate of the same batch as sample No. XI, in the preparation of standard samples to be used with his hysteresis tester. Taking B = 4,000 as the condition for reference, he finds values of the hysteresis loss in these samples ranging from 750 ergs per cycle down to 580 ergs per cycle. This last figure is the lowest amount of hysteresis loss the Author has hitherto found in any sample of iron or steel. It corresponds to 0·34 watt per lb. at a frequency of 100. If B = 2,500 were taken as the limit of the cycle the hysteresis of this "record" specimen would be only 0·16 watt per lb.

It may be useful to compare these results with those which were published by the Author in describing the first tests of hysteresis

[1] Journal of the Institution of Electrical Engineers, vol. xxiii. p. 224.

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ever made.[1] The tests in question were made in 1881 in the laboratory of the University of Tokio, using specimens of iron wire which the stock of the laboratory chanced to furnish. One of these was, mechanically, a particularly soft iron, and its hysteresis was found to have the following values:—

| Limits of Induction B. | Hysteresis Loss, Ergs per Cubic Centimetre per Cycle. | Watts per Lb. at a Frequency of 100. |
|---|---|---|
| 2,000 | 400 | 0·235 |
| 3,000 | 780 | 0 460 |
| 4,000 | 1,200 | 0·710 |
| 5,000 | 1,680 | 0·990 |
| 6,000 | 2,200 | 1·290 |
| 7,000 | 2,800 | 1·650 |
| 8,000 | 3,450 | 2·030 |
| 9,000 | 4,160 | 2·450 |
| 10,000 | 4,920 | 2·900 |
| 11,000 | 5,800 | 3·410 |
| 12,000 | 6,700 | 3·940 |

When transformers came into practical use a few years afterwards these results were often quoted, and it was generally remarked that they were smaller than the losses in the sheet-iron then obtainable for transformer cores.[2] The opinion was expressed that it was proper to add 50, 70 or even 90 per cent. to these figures in estimating the probable iron loss in a transformer. The Author himself found in most of the specimens of sheet and wire which then came into his hands considerably more hysteresis than in the accidentally good specimen tested in Japan. In 1893, however, he was able to give figures which in one specimen were not inferior to the Japanese standard.[3] From the results now published it is clear that the manufacture of sheet-iron for transformer has made a noteworthy advance during the last few years, in regard to the reduction of hysteresis in the iron. It is now practicable to obtain plates which are not only as good as the Japanese wire, but are far better. Taking B = 4,000 there was in the Japanese wire a loss of 1,200 ergs per cycle; in some of the best modern commercial iron this has been reduced, as we have just seen, to 800, 700, and even less than 600 ergs.

[1] Philosophical Transactions of the Royal Society, 1885, Part ii. pp. 555–6; Philosophical Magazine, vol. xvi. p. 381.

[2] Evershed and Vignoles, *The Electrician*, vol. xxix. p. 606.

[3] Philosophical Transactions of the Royal Society, 1893, p. 985; *The Electrician*, vol. xxxi. p. 623.

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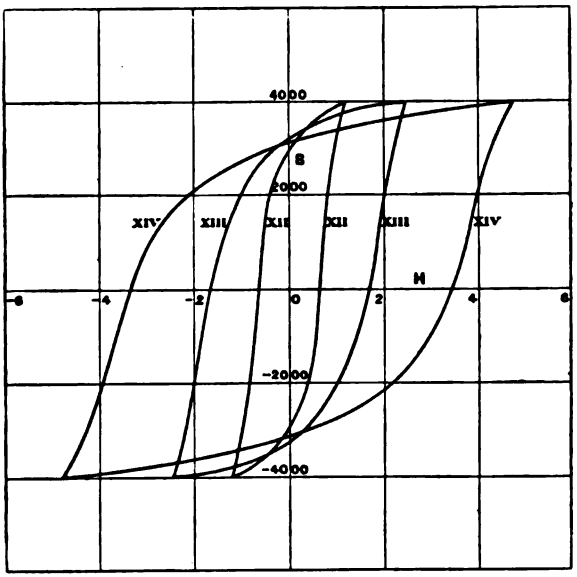
It is scarcely necessary to add that so much freedom from hysteresis is not found in all specimens of the iron that is even now used in transformers. The Author has recently found as much as 1,430 ergs (for B = 4,000) in plates supplied for this purpose. And a specimen taken out of a transformer, of no very ancient construction, gave 1,720 ergs. In both of these cases the original annealing of the plate appears to have been at fault, for a re-annealing of the specimens produced a marked improvement.

*Fig. 19* will serve as an additional illustration of the variations

*Fig. 19.*




in respect of hysteresis which are liable to be met with. The curves there show the cyclic process in three samples, in each case with 4,000 C.G.S. units as the limit of B, and the enclosed areas give the hysteresis. No. XII is a good specimen of transformer plate; No. XIII is a poor specimen, also supplied for use in transformers. No. XIV is an exceptionally bad material, which was supplied as soft iron, but which appears from the test to be a steel of by no means very mild quality.

These examples demonstrate the need of testing. To see that it is a matter of the highest practical importance to keep down the hysteresis, it is only necessary to remember that the work which

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is spent in reversing the magnetism of a transformer goes on continuously in the time when the transformer is giving no output as well as in the time when current is being taken from it. If the "load" under average conditions be reckoned as equivalent to full output for one and a half hours a day, an iron loss at the rate of 1 per cent. of the greatest output represents 16 per cent. of the total quantity of useful work done by the transformer. It is only under favourable conditions that the loss is as low as this. By accepting iron of poor quality, such as a few years ago was in general use, the loss may be more than doubled, and it does not need to be said that the doubling of so considerable a waste is a matter of moment in alternate-current supply.

The Paper is accompanied by eighteen tracings and two photographs, from which the *Figs.* in the text have been prepared.

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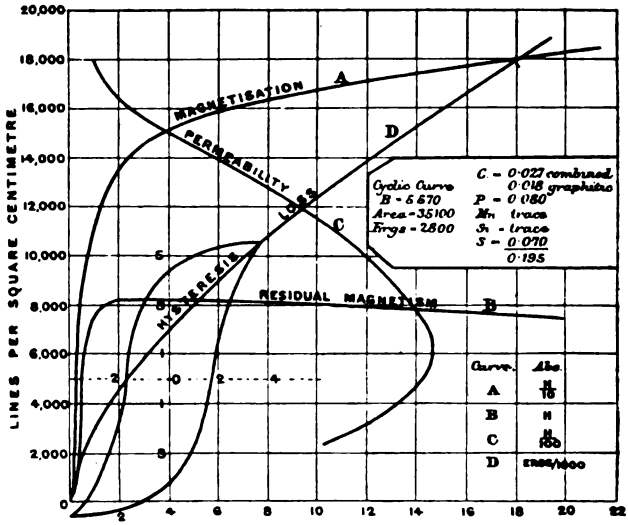
(*Paper No. 2973.*)

# "Magnetic Data of Iron and Steel."[1]

By HORACE FIELD PARSHALL, Assoc. M. Inst. C.E.

IN this Paper is given a summary of the results of tests of the magnetic properties of iron and steel of such compositions as are usually employed in the manufacture of electrical machinery. In Part I are shown the densities of magnetic flux, curve A, *Fig 1*, for

*Fig. 1.*




different magnetizing forces, and in Part II the losses by hysteresis, or inter-molecular friction, curve D, indicated by the area of the closed curve, *Fig. 1*. The magnetic properties of iron and steel depend upon the physical structure; as a primary indication of which, and as a specific basis for the description of material, chemical analysis forms an essential part of these tests. The physical structure, and the magnetic properties, are affected, to a

[1] The discussion upon this Paper was taken in conjunction with the preceding one, by Professor Ewing.

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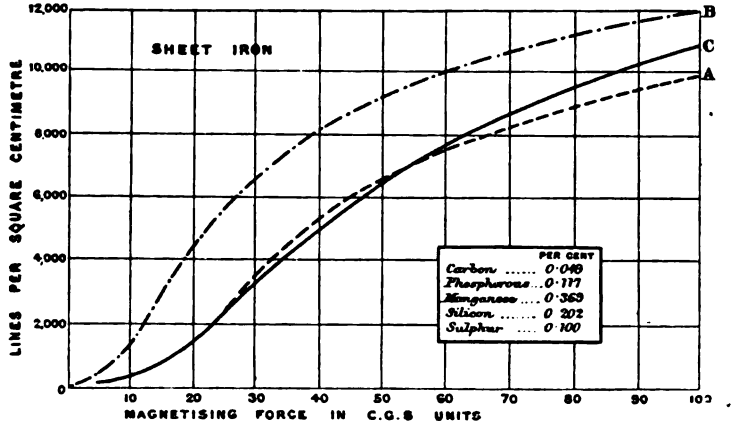
greater or less degree, according to the chemical composition, by annealing, tempering, continued heating, and mechanical strains by tension or compression. The rate of cooling also influences the magnetic properties of the material; the permeability of cast-iron, for instance, is diminished if the cooling has been too rapid, but it may be restored by annealing, the only noticeable change being that the size of the flakes of graphite is increased. The permeability of high-carbon steels may also be increased by annealing and diminished by tempering, and that of wrought-iron or steel is diminished by mechanical strain; the loss of permeability resulting from mechanical strain may, however, be restored by annealing. The curves A, B and C, *Fig. 2*, show the results of tests upon a particular sample of sheet-iron, as it was received from the makers, after it had been annealed, and after being

*Fig. 2.*




subjected to a pressure of 40,000 lbs. per square inch respectively. The effect on the magnetic properties of the different elements entering into the composition of iron and steel varies according to the percentage of other elements present. The presence of an element which alone would be objectionable may not be so when a number of others are present also; for instance, manganese, in ordinary amounts, is not objectionable in iron or steel, as the influence it exerts is of the same nature as that of carbon, but greatly less in degree. Some elements modify the influence of others, while some, although themselves objectionable, act as antidotes for more harmful impurities, as, for instance, in cast-iron silicon prevents the injurious influence of sulphur. The relative amount and the sum of the various elements varies slightly,

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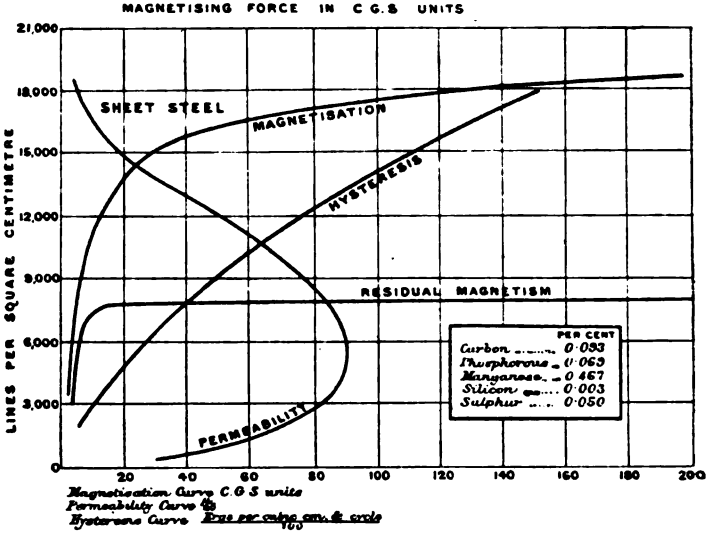
according to the slight variations in the process of manufacture. On account of the more or less unequal diffusion of the elements, a single analysis may not indicate the average quality, and may not, in extreme cases, fairly represent the quality of the sample used in the magnetic test. It is necessary, therefore, to make a great number of tests and analyses before arriving at an approximate result as to the effect of any one element. The conclusions given in the Paper as to the effect of various elements, when acting with the other elements generally present, were arrived at by studying the analysis and magnetic values when the amounts of all but one of the principal elements remained

*Fig. 3.*




constant. The results so obtained were compared with tests in which the elements that had remained constant in the first test varied in proportion. It will be seen that this method is only approximate, since variations of the amount of any element may modify the inter-actions between the other elements. The statements contained in this Paper have been compared with a great number of tests, and have been found correct within the limits between which materials can be economically produced in practice.

In general, the purer the iron or steel, the more important is the uniformity of the process and treatment, and the more difficult it is to predict the magnetic properties from the chemical analysis. It is significant to note that, beginning with the most impure

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cast-iron, and passing through the several grades of cast-iron, steel and wrought iron, the magnetic properties, accord principally with the amounts of carbon present and in a lesser degree with the proportions of sulphur, phosphorus, manganese, silicon and other less usual ingredients; and that an excess of any one, or of the sum of all the ingredients, has a noticeable effect on the magnetic properties. Carbon, on account of the influence it exerts on the melting-point, may be regarded as the controlling element, as it determines the general processes; hence also, the percentage of other elements present, in the purer grades of iron; however, its influence may be secondary to other impurities, as, for instance, in sheet-iron the influence of phosphorus on the hysteresis loss is more marked than that of any other element.

The properties of iron or steel require separate examination as to magnetic permeability and magnetic hysteresis. The permeability is of the greatest importance in parts in which there is small change in the magnetization; hence such parts may be of any desired dimension, and may then be either cast, rolled or forged. On account of the electrical losses by local currents when the magnetism is reversed in solid masses of metals, parts subject to hysteresis loss have to be finely laminated. Thicknesses of between 0·014 inch and 0·036 inch are generally found most useful for plates which must be of "good iron" to withstand the rolling process. Some impurities affect the hysteresis more than the permeability. Hysteresis tends towards a minimum and the permeability towards a maximum, as the percentage of elements, other than iron, diminishes. In the case of comparatively pure iron or steel alloyed with nickel, it is found, however, that the permeability is increased beyond that which would be inferred from the other elements present. The purest iron is found to have the highest permeability, yet the iron in which the hysteresis loss has been found smallest is not remarkable for its purity, and there was no known cause why the hysteresis was reduced to such a noticeable extent. The qualities of iron in which the hysteresis needs to be practically considered does not vary greatly in chemical analysis, so that special attention has to be paid to the treatment of the iron subsequent to its manufacture.

The tests as to permeability, and many of the tests as to hysteresis, were made by the Hopkinson methods. In some of the tests on the hysteresis loss the recent instruments of Mr. Holden and Professor Ewing have been used.[1] The C.G.S. system is

[1] *Ante*, p. 206.

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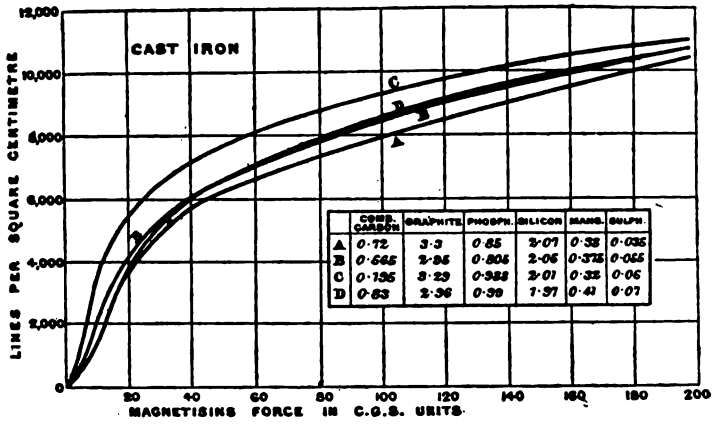
adopted throughout the Paper. The loss by hysteresis being expressed in "ergs per cubic centimetre per cycle."

## PART I.—THE MAGNETIZATION OF IRON AND STEEL.

*Cast-iron.*—Cast-iron is used for magnetic purposes on account of the great facility with which it may be made into castings of complex form. Considering the relative costs and magnetic properties of cast-iron and steel, as shown in the *Figs.*, it is evident that cast-iron is, other things being equal, more costly for a given magnetic result than cast steel. The great progress in the manufacture of steel castings has rendered the use of cast-iron exceptional in the construction of well-designed electrical

*Fig. 4.*




| | COMB. CARBON | GRAPHITE | PHOSPH. | SILICON | MANG. | SULPH. |
|---|---|---|---|---|---|---|
| A | 0·72 | 3·3 | 0·65 | 2·07 | 0·38 | 0·035 |
| B | 0·565 | 2·85 | 0·805 | 2·06 | 0·375 | 0·055 |
| C | 0·195 | 3·29 | 0·988 | 2·01 | 0·32 | 0·06 |
| D | 0·63 | 2·36 | 0·59 | 1·97 | 0·41 | 0·07 |

machines. The cast-iron used for magnetic purposes contains, to some extent, all those elements which crude iron brings with it from the ore, and from the fluxes and fuels used in its reduction. Of these elements, carbon has the greatest effect on the magnetic permeability. The amount of carbon present is, on account of the materials used, the processes employed, and its influence in determining the melting-point, necessarily high. In cast-iron of good magnetic quality the amount of carbon varies between 3 per cent. and 4½ per cent.; between 0·2 per cent. and 0·8 per cent. being in a combined state,[1] and the remainder in

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 15.

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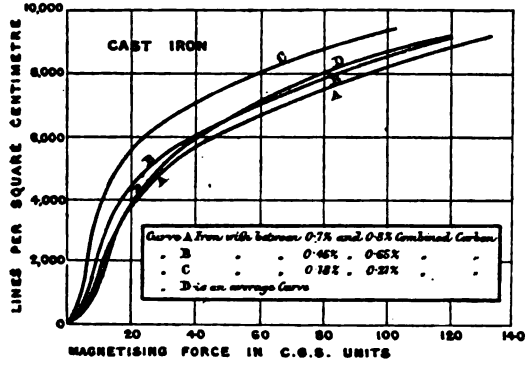
an uncombined or graphitic state. Combined carbon is the most objectionable ingredient, and should be restricted to as small an amount as possible. Cast-irons having less than 0·3 per cent. are generally found to be of high magnetic permeability. *Fig. 4* shows curves and analyses of four different grades of cast-iron. *Fig. 5* is to illustrate the effect of combined carbon. Graphite may vary between 2 per cent. and 3 per cent. without exerting any very marked effect on the permeability of cast-iron. It is generally found when the percentage of carbon approximates to the lower limit, there is an increase in the amount of combined carbon and a corresponding decrease of permeability. A certain percentage of carbon is necessary, and it is desirable that as much of it as possible should be in the graphitic state. Sulphur is

*Fig. 5.*




generally present, but only to a limited extent. An excess of sulphur is an indication of an excess of combined carbon and inferior magnetic quality. Silicon in excess, however, annuls the influence of sulphur, and does not seem to be objectionable until its amount is greater than 2 per cent.; the effect being to make a casting homogeneous and to lessen the amount of combined carbon. The amount of silicon generally varies between 2·5 per cent. in small castings and 1·8 per cent. in large castings. Phosphorus in excess denotes an inferior magnetic quality of iron. Although it may have no effect upon carbon, an excess of phosphorus is accompanied with an excess of combined carbon, and it should be restricted to 0·7 per cent. or 0·8 per cent. Manganese, in the proportions generally found, has but little effect; its influence becomes more marked in irons that are low in carbon, *Figs. 6* and *7*,



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which show further data relating to irons shown in *Fig. 5*, curves A and C respectively.

*Fig. 6.*

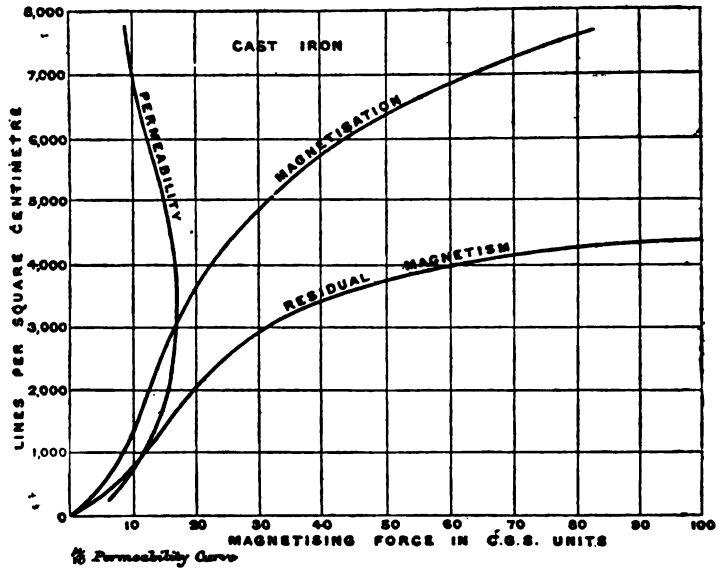
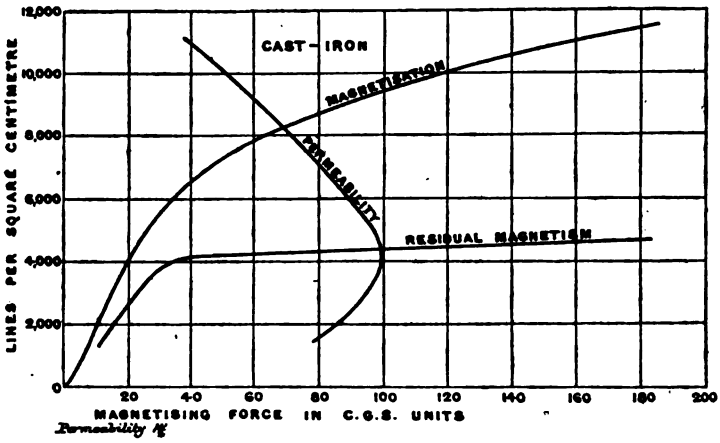



*Fig. 7.*




When cast-iron is de-carbonized, as in the process of malleableization, in which a portion of the graphite is eliminated, there is a marked increase in permeability. This is due, however,

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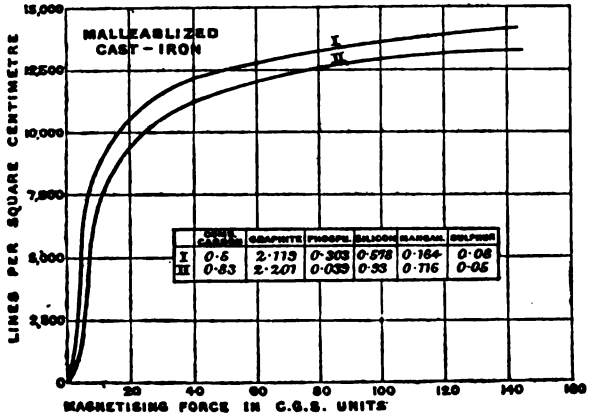
to the change in the physical structure of the iron which accompanies de-carbonization, as unmalleableized cast iron, of chemical

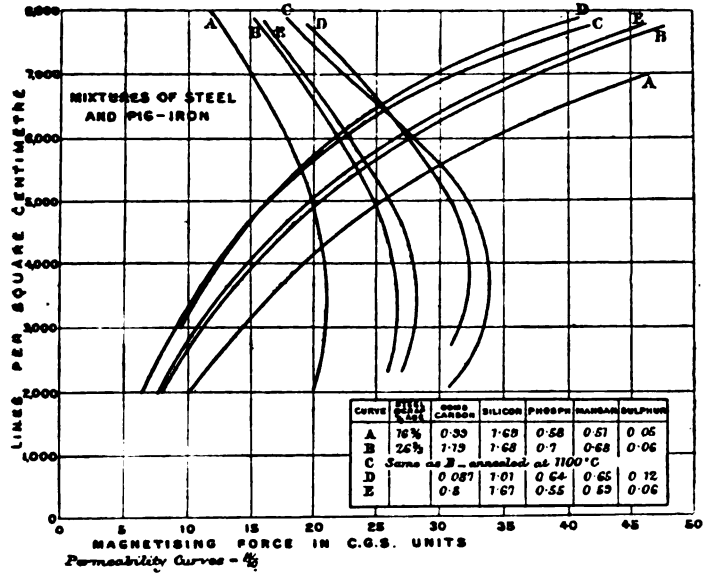
*Fig. 8.*




| | Total Carbon | Graphite | Phosph. | Silicon | Manganese | Sulphur |
|---|---|---|---|---|---|---|
| I | 0·5 | 2·113 | 0·303 | 0·578 | 0·164 | 0·08 |
| II | 0·83 | 2·201 | 0·039 | 0·33 | 0·716 | 0·05 |

analysis identical with that of malleable iron, has but a fraction of the permeability. In *Fig. 8* is shown the magnetic properties

*Fig. 9.*




| Curve | Steel % | Combined Carbon | Silicon | Phosphorus | Manganese | Sulphur |
|---|---|---|---|---|---|---|
| A | 76¾ | 0·39 | 1·69 | 0·58 | 0·51 | 0·05 |
| B | 26½ | 1·19 | 1·68 | 0·7 | 0·68 | 0·06 |
| C | *Same as B—annealed at 1100° C* | | | | | |
| D | | 0·087 | 1·01 | 0·64 | 0·65 | 0·12 |
| E | | 0·8 | 1·67 | 0·55 | 0·53 | 0·06 |

of malleableized cast-iron. *Fig. 9* illustrates the magnetic properties of mixtures of steel and pig iron.



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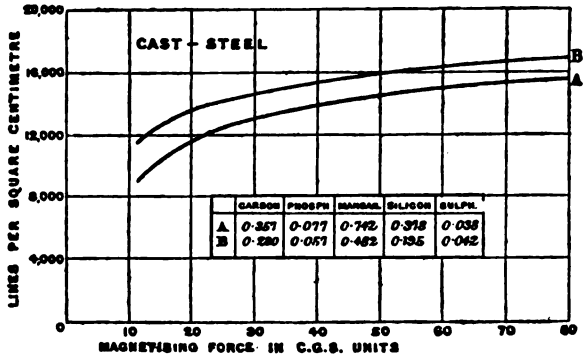
*Cast Steel.*—This term, as used in this Paper, is intended to refer to re-carbonized irons and not to the process of manufactures when there has been no re-carbonization, as in irons made by the steel process. Cast steel, used for magnetic purposes, has been generally made by the open-hearth or Siemens-Martin process; the principal reason being that this process has been more frequently used for the manufacture of small castings. The Bessemer process could, perhaps, be used to greater advantage in the manufacture of small castings than the open-hearth process, since, on account of the considerable time elapsing between the pouring of the first and last castings, there is frequently, by the open-hearth process, a change of temperature in the molten steel, and likewise a noticeable difference in the magnetic quality. In the Bessemer process, the metal can be maintained at the most

*Fig. 10.*




suitable temperature and the composition may be more easily regulated.

Cast steel is distinguishable by the very small amount of carbon present, which is in the combined state, there being generally no graphite present, as in the case of cast iron, the exception being when castings are subjected to great strains, in which case the combined carbon partly changes to graphite. It may be approximately stated that good cast steel, from a magnetic standpoint, should not have greater percentages of impurities than the following:—

| | Per Cent. |
|---|---|
| Combined carbon | 0·25 |
| Phosphorus | 0·08 |
| Silicon | 0·20 |
| Manganese | 0·50 |
| Sulphur | 0·05 |

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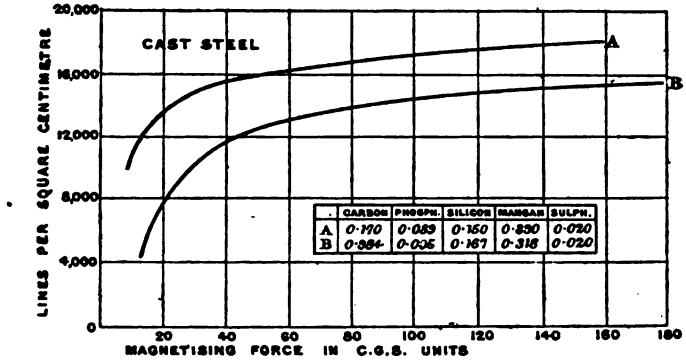
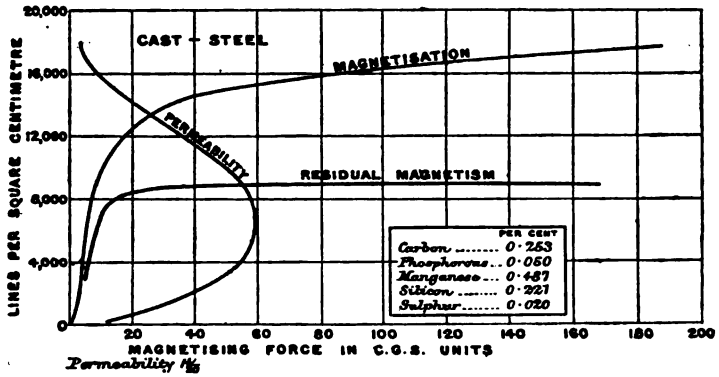
In practice, carbon is the most objectionable impurity, and may be with advantage restricted to smaller amounts than 0·25 per cent. The results of a great number of tests and analyses show that the decrease in the permeability is proportional to the amount

*Fig. 11.*




of carbon in the steel, other conditions remaining equal, that is, that the other elements are present in the same proportion, and that the temperature of the molten steel is increased according to the degree of purity. Steel cast at too low a temperature,

*Fig. 12.*




considering the state of purity, shows a lower permeability than would be inferred from the analysis. Manganese in amounts less than 0·5 per cent. has but little effect upon the magnetic properties of ordinary steel. In large proportions, however, it deprives

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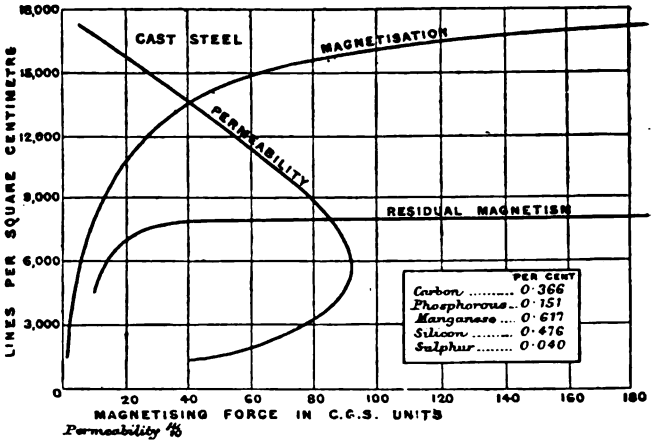
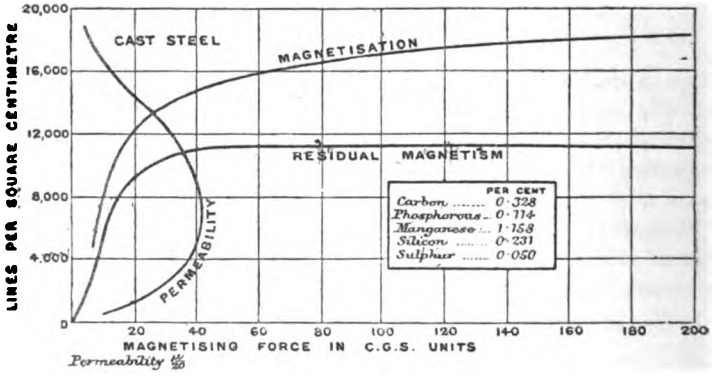
steel of nearly all its magnetic properties, a 12 per cent. mixture scarcely having greater permeability than air. Silicon, at the magnetic densities economical in practice, is less objectionable

*Fig. 13.*




than carbon; but, at high densities, it diminishes the permeability to a noticeable extent. The objection to silicon is that, when unequally diffused, it facilitates the formation of blow-holes, and, like manganese, has a hardening effect, rendering the steel difficult

*Fig. 14.*




to tool in machining. Phosphorus and sulphur, in the amounts specified, are not objectionable; in excess, however, they generally render the steel of inferior magnetic quality.

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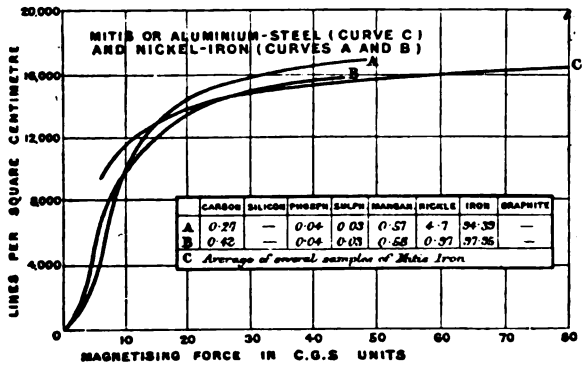
In Table I, Appendix I, are given the analyses and magnetic properties of what may be termed "good steel;" and in Table II are shown analyses and magnetic properties of what may be termed "inferior steel." The mean or average values are given in *Fig. 10*. In *Fig. 11* is shown the effect of combined carbon on the magnetic properties; the magnetic properties of steel are further illustrated in *Figs. 12* to *14*.

In Table III, Appendix I, are given analyses and magnetic properties of aluminium steel, frequently known as "Mitis iron." The action of aluminium in steel is, like that of silicon, sulphur, or phosphorus, of a softening nature. It seems to act more powerfully than silicon, the result in castings being a somewhat greater degree of purity, and a higher magnetic quality than in steel made by processes of equal refinement. Some of the

*Fig. 15.*




alloys of steel with nickel possess remarkable magnetic properties.[1] A 5 per cent. mixture of nickel with steel shows a greater permeability than can be accounted for by the analysis or the properties of either the steel or the iron. The properties of nickel alloys and mitis iron are shown in *Fig. 15*.[2]

*Wrought Iron.*—Forgings of wrought iron are, in practice, found to be of uniform quality and of high magnetic permeability. The variation is rarely more than 5 per cent. In curves A and E, *Fig. 16*, are shown the magnetic properties of wrought iron,

[1] For information as to the remarkable conditions controlling the magnetic properties of the alloys of nickel and iron, see Dr. J. Hopkinson, Proceedings of Royal Society, vol. xlvii. p. 23, and vol. xlviii. p. 1.

[2] Various investigations have shown that the permeability of steel is greatly lessened by the presence of chromium and tungsten.

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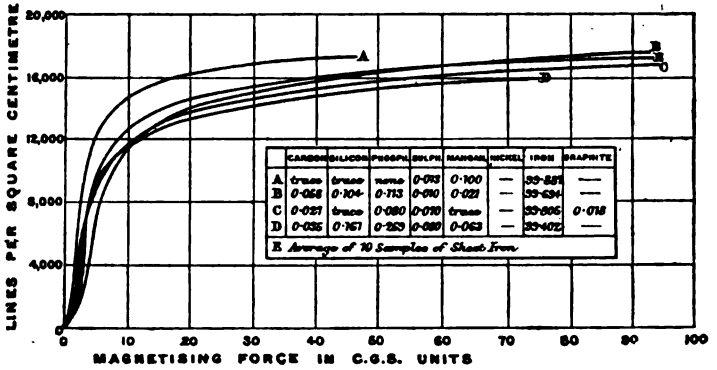
nearly pure, and as generally obtained respectively. The former is made by the steel process at the Elswick Works of Messrs. Sir W. G. Armstrong & Co., Ltd.[1]; but, owing to its excessively high melting-point, it is only manufactured for exceptional purposes. In curves C and D is illustrated a grade of wrought iron somewhat inferior to that of E, the lower permeability being satisfactorily accounted for by the excess of phosphorus and sulphur. Curve C shows the properties of a forging of Swedish iron, in the analysis of which it is somewhat remarkable to find a small percentage of graphite.

## Part II.—Energy Losses in Sheet-iron.

The energy loss in sheet-iron in an alternating or rotating magnetic field consists of two distinct quantities, (1) that by

*Fig. 16.*




hysteresis or inter-molecular magnetic friction, and (2) that by eddy currents. The loss by hysteresis is proportional to the frequency of the reversal of the magnetism, but is entirely independent of the thickness of the iron, and increases with the magnetization. There is no exact law of the increase of the hysteresis with the magnetization, but, within the limits of magnetization obtaining in practice, and those in which such material can be produced to give uniform results, the energy loss by hysteresis may be taken to increase approximately with the 1·6th power of the magnetization, as was first pointed out by

[1] "On the Magnetic Properties of Pure Iron," by Messrs. Lydall and Pocklington. Proceedings of the Royal Society, vol. lii. p. 228.

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Mr. C. P. Steinmetz.[1] The loss by eddy currents is proportional to the square of the frequency of reversal, the square of the magnetization, and the square of the thickness of the iron plates, and is given by the formula—

$$W = 0{\cdot}000146\ B^2 N^2 d^2,$$

where W is the loss in ergs per cubic centimetre per cycle, N, the number of complete cycles, and $d$ the thickness of the plate in centimetres. It depends upon the electrical conductivity of the material, and does not properly form any part of the discussion; but for completeness the *Figs. 17* and *18* are given to show the magnitude of the electrical losses under different conditions, so that comparisons as to the relative proportions, in any given case, of this loss to the hysteresis loss can be determined. The losses decrease about 10 per cent. for every 25° C. rise of temperature.

Investigations as to the nature of the hysteresis loss show that it is the same whether the magnetism rotates through the iron, as in the case of a dynamo, or is simply reversed, as in the case of an alternating-current transformer. It is a well-established fact that the loss by hysteresis in this last case varies with a given effective impressed electromotive-force in the magnetizing circuit, according to the impressed electromotive-force curve. This does not, however, prove that the hysteresis loss is determined by other conditions than the maximum flux-density in a cycle, and that the hysteresis loss is affected by the nature of the reversal. The mean square of one form of curve, as also the mean ordinate, differs greatly from that of another. Measurements of energy losses in transformers, and the maximum magnetization, have to be considered with respect to the form of the impressed electromotive-force curve. A complete investigation in this case involves measurements of the instantaneous values of both the current and the electromotive force. The area of the loop, with the magnetizing force as abscissas, and the magnetization as ordinates, represents the energy dissipated by molecular magnetic friction, when the iron does not receive energy except that expended in the magnetizing circuit. If, as in the case of a rotating armature, the iron is subjected to mechanical vibration, the dissipation of energy by molecular magnetic friction remains the same; but such vibration may cause, in an actual test, the collapse of the hysteretic loop, and consequently the area of the hysteretic loop in such cases does not represent the amount of the magnetic frictional loss.

[1] *Electrical Engineer*, New York, vol. x. p. 677.

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The sheet iron generally used in electrical manufacture is either 0·014 inch, 0·025 inch, or 0·036 inch thick, and between 36 inches

*Fig. 17.*

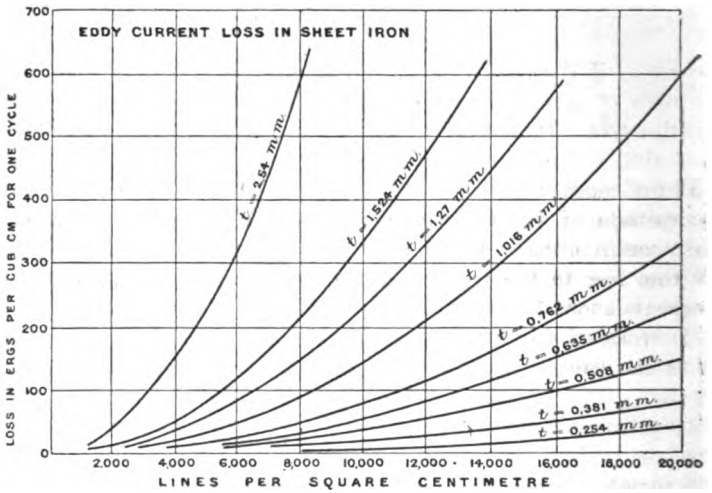
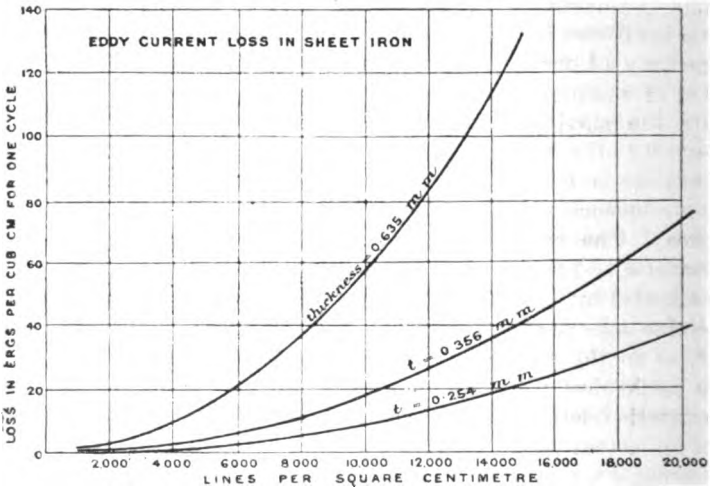

EDDY CURRENT LOSS IN SHEET IRON
LOSS IN ERGS PER CUB CM FOR ONE CYCLE
LINES PER SQUARE CENTIMETRE
t = 2.54 m.m.
t = 1.524 m.m.
t = 1.27 m.m.
t = 1.016 m.m.
t = 0.762 m.m.
t = 0.635 m.m.
t = 0.508 m.m.
t = 0.381 m.m.
t = 0.254 m.m.

*Fig. 18.*


EDDY CURRENT LOSS IN SHEET IRON
LOSS IN ERGS PER CUB CM FOR ONE CYCLE
LINES PER SQUARE CENTIMETRE
thickness = 0.635 m.m.
t = 0.356 m.m.
t = 0.254 m.m.

and 45 inches in width. Such plates are rolled from either acid open-hearth steel, basic open-hearth steel, or charcoal iron. The

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maximum percentage of impurities allowable in good practice in such sheet irons are shown in the following Table :—

| | Acid Open-hearth Steel. | Basic Open-hearth Steel. | Charcoal Iron. |
|---|---|---|---|
| Carbon . . . . | 0·08 | 0·08 | 0·05 |
| Silicon . . . . | 0·01 | 0·01 | 0·05 |
| Phosphorus . . . | 0·08 | 0·05 | 0·08 |
| Manganese . . . | 0·40 | 0·40 | 0·06 |
| Sulphur . . . . | 0·05 | 0·05 | 0·03 |

For the properties of charcoal iron, see *Fig. 16*, curve E.
„ „ sheet steel, see *Fig. 3*.

The chemical analysis of the steel differs very little from that of the wrought iron ordinarily rolled into these plates. In general, plates made by the steel process show more manganese, and those made by the iron process show more silicon, these being the clues which, in practice, may serve to identify the processes.

It is most difficult to determine the effect of the chemical constituents upon the hysteresis loss in sheet-iron and steel, owing to the fact that, with the usual compositions low in silicon, a very slight difference in the annealing will make a disproportionately great difference in the hysteresis loss; and it is a matter of great difficulty to subject different samples in different tests to similar conditions in annealing. It is hard to eliminate this large variable effect sufficiently accurately to determine at all satisfactorily the residual effects of the chemical constituents. Annealing has a tendency to make the structure of the iron more homogeneous; experiments having been made to show that hysteresis, at a density of 8,000 lines per square centimetre, can be lessened from 8,000 ergs per cubic centimetre per cycle to about 2,000, by careful and continuous annealing, the effect of which in several samples of sheet-iron is shown in the annexed Table :—

EFFECTS OF ANNEALING ON THE HYSTERESIS LOSS, IN ERGS PER CUBIC CENTIMETRE PER CYCLE AT A DENSITY OF 8,000 LINES PER SQUARE CENTIMETRE.

| Unannealed. | Annealed. |
|---|---|
| 3,900 | 3,300 |
| 4,200 | 3,100 |
| 4,900 | 4,200 |
| 4,800 | 3,300 |
| 4,050 | 3,200 |
| 3,400 | 2,800 |
| 3,650 | 2,900 |
| 5,010 | 3,700 |
| 3,900 | 3,100 |
| 3,900 | 3,300 |
| 3,650 | 3,100 |
| 3,650 | 2,900 |

Referring next, specifically, to the effects of impurities in wrought-iron on the hysteresis loss, it may be stated that the presence of any impurity in iron is probably objectionable, but the inter-actions between the elements, as they occur in the iron especially manufactured for small hysteresis loss, that is to say, in irons of between 99·2 per cent. and 99·8 per cent. purity, the slight variations in chemical

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analysis do not indicate the properties of the iron as to the hysteresis loss. Samples of precisely the same chemical analysis, and which have, as far as possible, been subjected to the same treatment, are found to differ greatly. Between the limits specified, a greater degree of purity does not indicate superiority. The conclusions warranted by the tests indicate that silicon, in the amounts occurring in sheet-iron and steel, is not particularly harmful, except that it tends to prevent, to a certain extent, the improvement that would otherwise occur from annealing. Manganese and sulphur, in amounts not exceeding 0·5 per cent. and 0·06 per cent. respectively, do not increase the hysteresis loss. Phosphorus is especially objectionable, as regards the hysteresis loss, and has, proportionately, a greater effect than carbon.

In the two following Tables are shown, respectively, the results of hysteresis tests of six samples of iron proved of good quality, and six samples of inferior quality. The average of the latter Table shows somewhat larger percentages of all the impurities

Results of Hysteresis Tests of Samples of Good Iron.

| — | 1 | 2 | 3 | 4 | 5 | 6 | Average. |
|---|---|---|---|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Material . . . | Sheet Iron | .. | .. | .. | .. | .. | .. |
| Carbon . . . . | 0·076 | 0·085 | 0·072 | 0·086 | 0·095 | 0·078 | 0·082 |
| Phosphorus . . . | 0·058 | 0·052 | 0·057 | 0·084 | 0·075 | 0·056 | 0·064 |
| Silicon . . . . | Trace | 0·005 | 0·006 | Trace | 0·007 | 0·012 | 0·005 |
| Manganese . . . | 0·297 | 0·021 | 0·417 | 0·320 | 0·322 | 0·026 | 0·246 |
| Sulphur . . . . | 0·060 | 0·030 | 0·030 | 0·040 | 0·030 | 0·010 | 0·033 |
| Ergs per cubic cm. per cycle at a density of 8,000 lines per sq. cm. | 2,800 | 3,100 | 2,800 | 3,000 | 3,300 | 3,400 | 3,070 |

Results of Hysteresis Tests of Six Samples of Inferior Iron.

| — | 1 | 2 | 3 | 4 | 5 | 6 | Average. |
|---|---|---|---|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Material . . . | .. | .. | Sheet Iron | Sheet Iron | Sheet Steel | Sheet Steel | .. |
| Carbon . . . . | 0·153 | 0·063 | 0·117 | 0·099 | 0·090 | 0·153 | 0·113 |
| Phosphorus . . . | 0·032 | 0·075 | 0·101 | 0·135 | 0·101 | 0·031 | 0·088 |
| Silicon . . . . | 0·007 | 0·008 | 0·005 | 0·000 | 0·027 | 0·002 | 0·008 |
| Manganese . . . | 0·430 | 0·036 | 0·401 | 0·449 | 0·449 | 0·486 | 0·375 |
| Sulphur . . . . | 0·050 | 0·030 | 0·010 | 0·030 | 0·030 | 0·070 | 0·045 |
| Ergs per cubic cm. per cycle at a density of 8,000 lines per sq. cm. | 8,300 | 9,000 | 8,500 | 8,050 | 8,000 | 8,000 | 8,310 |

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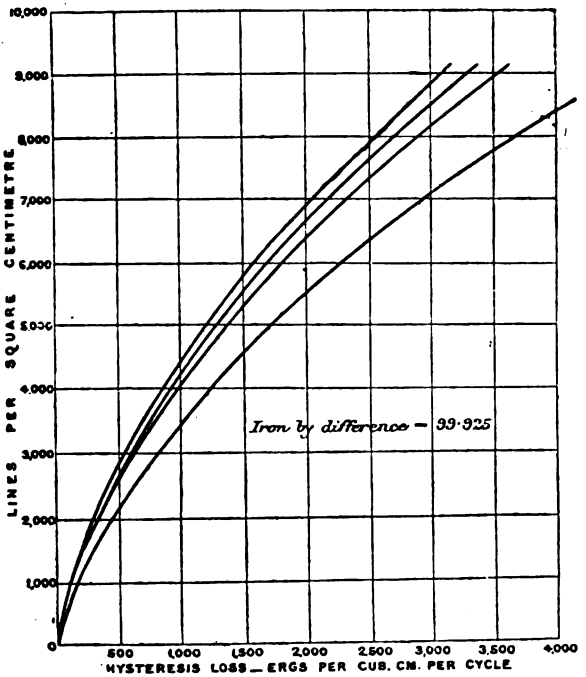
than that of the former. The poor results of the latter, as well as the better results of the former, are undoubtedly due largely to the difference in the annealing.

It has been found that, in the use of transformers, the hysteresis loss in iron increases by continued heating.[1] Some irons deteriorate more from this cause than others, and some of the best samples tested by the Author have deteriorated more rapidly than samples that were not so good at the start. The degree of purity does not indicate the rate with which iron will de-

*Fig. 19.*




CURVES SHOWING HYSTERESIS LOSS IN WROUGHT IRON.

teriorate under the influence of heating. Some samples of very pure iron, made by the iron process, have been found to deteriorate to a much greater extent than less pure irons made by the steel process. An examination of the chemical analysis only indicates a difference in the percentage of silicon present, this

[1] "On Slow Changes in the Magnetic Permeability of Iron," by Mr. W. M. Mordey, Proceedings of the Royal Society, vol. lvii. p. 224.

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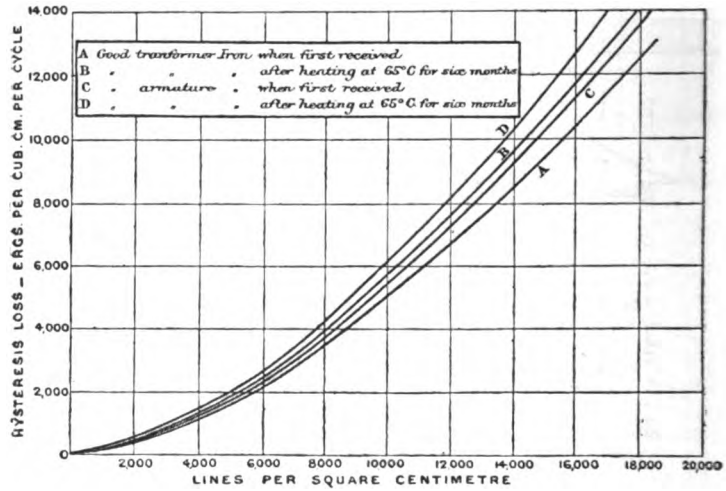
being to excess in the charcoal iron. Whether or not this deterioration can be charged to the silicon cannot yet definitely be stated. Iron which has deteriorated from continued heating may be restored to its original state by annealing; and especially good iron, after continued annealing, may deteriorate from heating, so that, in practice, it will ultimately be found inferior to iron originally not so good. In Appendix II are shown the results of annealing and subsequent deterioration of a number of samples of iron at different temperatures. The hysteresis loss in four exceptionally good samples of wrought-iron is shown in *Fig. 19*. This wrought-iron, which was manufactured with the greatest care, and, as

*Fig. 20.*




CURVES SHOWING HYSTERESIS LOSS IN TRANSFORMER AND ARMATURE IRON.

nearly as possible, by uniform process and treatment, and contains 99·925 per cent. of iron, was found to deteriorate 25 per cent. after heating at 85° C. for one week. In *Fig. 20* are shown, for transformer iron and armature iron, the best results that may be expected of iron in bulk when first received, and after being heated for six months at 65° C.

A great number of conditions have therefore to be considered with respect to the hysteresis loss in wrought-iron sheets, and there may be a great discrepancy between the tests made of material before used and that actually found in practice. The following curves are therefore given, which have been deduced from a great number of tests on transformers and dynamos. In

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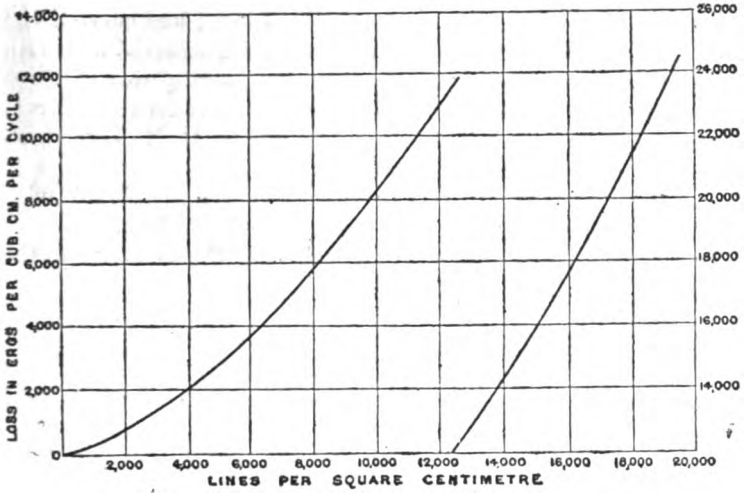
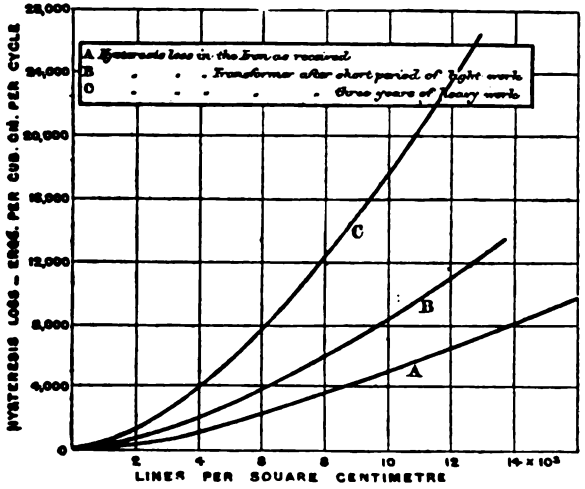
*Fig. 21* is shown the loss by hysteresis in dynamo armatures. This curve is a mean of some hundreds of tests on smooth-core

*Fig. 21.*




CURVES SHOWING HYSTERESIS LOSS IN SHEET-IRON.

*Fig. 22.*




CURVES SHOWING DETERIORATION OF IRON IN TRANSFORMERS.

armatures, so that the additional loss by eddy currents in the pole-pieces found in the use of projecting armatures is eliminated.

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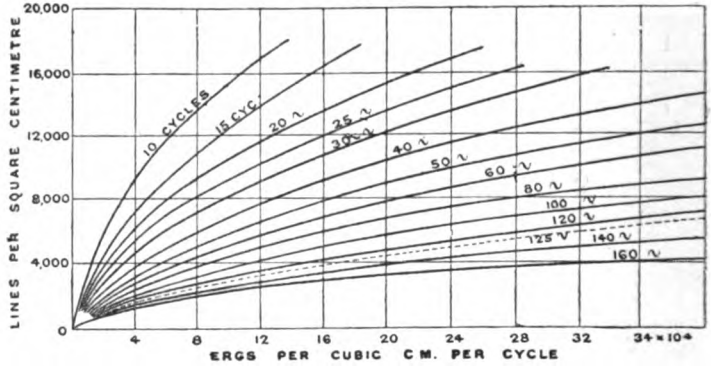
In *Fig. 22* are given curves showing what some qualities of iron may come to in use in transformers subjected to abnormal conditions. Curve A shows the result of the test of hysteresis loss upon the iron as received; curve B shows the loss in a new transformer, made from the same quality of iron; and curve C the core loss in a transformer made from the same material and with the same care, having performed heavy duty for a period of three or four years. In *Fig. 23* is given an exhaustive series of curves of tests as to the total iron loss, made by Mr. H. M. Hobart, on transformers artificially cooled and maintained at a low temperature. It will be noticed that these iron losses agree closely with the values given for the best quality of commercial iron.

In conclusion, the Author would point out the necessity to the

*Fig. 23.*




CURVES SHOWING TOTAL IRON LOSSES IN ARTIFICIALLY COOLED TRANSFORMERS.

manufacturer of knowing the conditions which iron is to be subjected to in use. Without this knowledge, a guarantee as to the hysteresis loss is of little practical value. On the part of the electrical manufacturer, he would emphasize the necessity of studying the processes of manufacture of iron in connection with the magnetic results, and that the conditions to which the iron is subject be conformed with reference to the properties of the iron after continued use, and not with respect to the iron when in an initial state, and that the design for a transformer or dynamo, for the highest possible efficiency, when new, may be, and frequently is, to the ultimate disadvantage of the user.

The Paper is accompanied by tracings from which the *Figs.* in the text have been prepared.

[APPENDIXES.

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# APPENDIXES.

## APPENDIX I.

TABLE I.—DATA OF TEN FIRST QUALITY SAMPLES OF CAST STEEL.

| —— | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | Average. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B for H = 15 . . . . . | 12,200 | 12,000 | 12,100 | 12,900 | 13,000 | 12,300 | 13,100 | 12,100 | 12,600 | 13,000 | 12,500 |
| B for H = 25 . . . . . | 14,100 | 13,600 | 13,900 | 14,400 | 14,600 | 13,900 | 14,500 | 13,700 | 14,200 | 14,500 | 14,100 |
| B for H = 50 . . . . . | 15,800 | 15,300 | 15,600 | 15,900 | 16,600 | 15,600 | 16,100 | 15,400 | 15,800 | 16,000 | 15,800 |
| B for H = 75 . . . . . | 16,600 | 16,200 | 16,600 | 16,500 | 17,600 | 16,400 | 17,100 | 16,300 | 16,700 | 16,600 | 16,700 |
| Carbon . . . . . | 0·240 | 0·267 | 0·294 | 0·180 | 0·290 | 0·250 | 0·200 | 0·230 | 0·170 | 0·180 | 0·230 |
| Phosphorus . . . . . | 0·071 | 0·052 | 0·074 | 0·047 | 0·037 | 0·093 | 0·047 | 0·100 | 0·089 | 0·047 | 0·057 |
| Silicon . . . . . | 0·200 | 0·236 | 0·202 | 0·120 | 0·036 | 0·230 | 0·170 | 0·160 | 0·150 | 0·120 | 0·195 |
| Manganese . . . . . | 0·480 | 0·707 | 0·655 | 0·323 | 0·550 | 0·410 | 0·530 | 0·450 | 0·390 | 0·323 | 0·482 |
| Sulphur . . . . . | 0·040 | 0·060 | 0·050 | 0·050 | 0·050 | 0·030 | 0·030 | 0·040 | 0·020 | 0·050 | 0·042 |

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TABLE II.—DATA OF TEN SECOND QUALITY SAMPLES OF CAST STEEL.

| —— | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | Average. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B for H = 15 . . . . . | 10,600 | 10,600 | 10,700 | 9,000 | 9,300 | 10,000 | 10,400 | 10,000 | 9,300 | 11,300 | 10,120 |
| B for H = 25 . . . . . | 12,700 | 12,700 | 13,100 | 11,200 | 11,600 | 12,100 | 12,500 | 12,400 | 11,800 | 13,500 | 12,360 |
| B for H = 50 . . . . . | 14,900 | 14,600 | 15,100 | 13,500 | 13,900 | 14,300 | 14,400 | 14,700 | 14,100 | 15,700 | 14,590 |
| B for H = 75 . . . . . | 15,900 | 15,600 | 15,900 | 14,400 | 14,900 | 15,300 | 15,300 | 15,700 | 15,000 | 16,500 | 15,450 |
| Carbon . . . . . | 0·250 | 0·280 | 0·195 | 0·333 | 0·337 | 0·366 | 0·409 | 0·318 | 0·702 | 0·380 | 0·357 |
| Phosphorus . . . . . | 0·087 | 0·076 | 0·028 | 0·059 | 0·045 | 0·151 | 0·063 | 0·107 | 0·084 | 0·066 | 0·077 |
| Silicon . . . . . | 0·210 | 0·210 | 0·683 | 0·292 | 0·302 | 0·476 | 0·444 | 0·203 | 0·409 | 0·550 | 0·378 |
| Manganese . . . . . | 0·790 | 0·720 | 0·815 | 0·681 | 0·642 | 0·617 | 0·640 | 1·636 | 0·088 | 0·790 | 0·742 |
| Sulphur . . . . . | 0·020 | 0 030 | 0·040 | 0·060 | 0·070 | 0·040 | 0·010 | 0·030 | 0·050 | 0·030 | 0·038 |

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TABLE III.—DATA OF TWELVE SAMPLES OF MITIS IRON.

| —— | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | XI. | XII. | Average. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B for H = 15 . . . . | 12,600 | 14,500 | 14,500 | 12,700 | 13,900 | 14,200 | 14,000 | 10,800 | 10,000 | 12,900 | 12,700 | 11,800 | 12,900 |
| B for H = 25 . . . . | 13,600 | 15,600 | 15,700 | 14,500 | 15,000 | 15,700 | 15,300 | 12,650 | 11,900 | 14,300 | 14,300 | 13,400 | 14,300 |
| B for H = 50 . . . . | 14,800 | 16,900 | 16,700 | 16,200 | 16,300 | 16,800 | 16,500 | 14,300 | 13,900 | 15,900 | 16,000 | 15,000 | 15,800 |
| B for H = 75 . . . . | 15,500 | 17,600 | 17,500 | 16,900 | 17,000 | 17,400 | 17,100 | 15,200 | 14,800 | 16,800 | 16,800 | 15,700 | 16,500 |
| Carbon . . . . . | 0·065 | 0·105 | 0·106 | 0·125 | 0·136 | 0·212 | 0·214 | 0·216 | 0·235 | 0·241 | 0·242 | 0·260 | 0·180 |
| Phosphorus . . . . | 0·083 | 0·093 | 0·112 | 0·166 | 0·053 | 0·056 | 0·052 | 0·128 | 0·065 | 0·093 | 0·094 | 0·120 | 0·093 |
| Silicon . . . . . | 0·073 | 0·045 | 0·050 | 0·046 | 0·111 | 0·126 | 0·111 | 0·083 | 0·122 | 0·072 | 0·099 | 0·020 | 0·080 |
| Manganese . . . . | 0·112 | 0·108 | 0·099 | 0·120 | 0·191 | 0·405 | 0·401 | 0·167 | 0·107 | 0·248 | 0·253 | 0·140 | 0·196 |
| Sulphur . . . . . | 0·150 | 0·050 | 0·050 | 0·050 | 0·030 | 0·040 | 0·040 | 0·010 | 0·030 | 0·030 | 0·030 | 0·030 | 0·045 |
| Aluminium . . . . | 0·079 | Not determined | 0·059 | 0·183 | 0·008 | 0·273 | Not determined | 0·152 | 0·055 | 0·120 | 0·119 | 0·080 | 0·113 |



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## APPENDIX II.

### Tests in Deterioration of Iron.

The hysteretic loss is given in ergs per cubic centimetre per cycle at 8,000 lines.

| Unannealed. | Annealed. | After continued heating for | | | | Increase Per Cent. | — |
|---|---|---|---|---|---|---|---|
| | | 10 days. | 30 days. | 100 days. | 180 days. | | |
| | | | | | | | °C. |
| 3,900 | 3,300 | 3,950 | 3,950 | 3,950 | 3,950 | 1·2 | 25 |
| 3,900 | | 3,300 | 3,300 | 3,300 | 3,300 | 0·0 | 25 |
| 4,400 | 3,100 | 4,450 | 4,550 | 4,700 | 4,800 | 9·1 | 65 |
| 4,200 | | 3,200 | 3,300 | 3,400 | 3,500 | 12·9 | 65 |
| 4,350 | 4,200 | 4,400 | 4,500 | 4,650 | 4,750 | 9·2 | 85 |
| 4,900 | | 4,300 | 4,500 | 4,700 | 4,800 | 14·3 | 85 |
| 4,450 | 3,300 | 4,450 | 4,450 | 4,500 | 4,500 | 1·1 | 125 |
| 4,800 | | 3,500 | 3,700 | 3,850 | 3,900 | 18·2 | 125 |
| 3,800 | 3,200 | 3,800 | 3,810 | 3,900 | 3,900 | 2·6 | 25 |
| 4,050 | | 3,200 | 3,200 | 3,200 | 3,200 | 0·0 | 25 |
| 3,800 | 2,800 | 3,800 | 3,800 | 3,900 | 3,900 | 2·6 | 65 |
| 3,400 | | 2,800 | 2,850 | 2,900 | 2,900 | 3·6 | 65 |
| 3,900 | 2,900 | 3,900 | 3,900 | 3,900 | 3,900 | 0·0 | 25 |
| 3,650 | | 2,950 | 3,000 | 3,000 | 3,000 | 3·4 | 25 |
| 3,800 | 3,700 | 3,800 | 3,850 | 3,900 | 3,900 | 2·6 | 25 |
| 5,010 | | 3,700 | 3,750 | 3,750 | 3,750 | 1·3 | 25 |
| 3,900 | 3,100 | 3,900 | 4,050 | 4,400 | 4,600 | 18·0 | 65 |
| 3,900 | | 3,200 | 3,400 | 3,800 | 4,000 | 29·0 | 65 |
| 4,900 | 3,300 | 4,950 | 5,050 | 5,400 | .. | .. | 65 |
| 3,900 | | 3,500 | 3,650 | 3,900 | .. | .. | 65 |
| 3,750 | 3,100 | 3,800 | 4,050 | 4,300 | 4,350 | 15·0 | 85 |
| 3,650 | | 3,150 | 3,300 | 3,750 | 3,750 | 18·0 | 85 |
| 3,700 | 2,900 | 3,750 | 3,800 | 4,050 | 4,050 | 9·5 | 125 |
| 3,650 | | 3,050 | 3,200 | 3,500 | 3,550 | 22·0 | 125 |

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## Discussion.

Sir BENJAMIN BAKER, President, moved a vote of thanks to Professor Ewing (one of the highest authorities on the subject he had treated) for his valuable Paper, and it was an equal pleasure to propose a similar acknowledgment to Mr. Parshall. Although the members might not be able to follow the whole of Mr. Parshall's Paper, every engineer would know that twenty-three diagrams like those exhibited could not be prepared without an infinite amount of trouble and pains in obtaining the data for the different curves. Sir Benjamin Baker.

Professor EWING exhibited two instruments, referred to in the Paper, designed with the object of making hysteresis and permeability tests in a manner much more expeditious, and therefore better suited for workshop purposes, than was possible by the use of the familiar ballistic method. In the Paper there was fully described the ballistic method and the various modifications of it, which had been introduced by Dr. Hopkinson and others with excellent effect, for measuring the magnetic qualities of iron. It was perfectly possible, by means of the ballistic method, to make complete observations both of magnetic permeability and of magnetic hysteresis; but the process was necessarily a laborious one, and required a certain amount of scientific training. It was obviously an advantage if, for the purposes of the workshop, the points of vital importance in regard to the magnetic quality of iron could be determined in some more simple and expeditious way. He had endeavoured to achieve that result by the design of these two instruments, one of which, the hysteresis tester, had been fully described in the Paper, and was shown in *Fig. 15*. He placed in the instrument upon the table two samples, one of which he knew beforehand to be a very good specimen of transformer sheet iron, and the other a very bad one. Having inserted the good specimen he would turn it in one direction and then to the other, and the amount of deflection would be observed. He revolved the specimen one way and obtained a deflection of 22 scale divisions. Reversing the direction of the revolution he observed a deflection of 24 scale divisions. The sum of those two deflections might be taken as representing the hysteresis of the specimen. Removing the specimen and substituting the other and causing it to revolve in the same manner, it was found that the deflection on one side Prof. Ewing.

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Prof. Ewing. was 77 divisions, and when reversing the direction of the rotation 76 divisions, and the sum of those two numbers might be taken to represent the hysteresis of that specimen. The figures were subject to a small correction which he need not enter into. Subject to that, the two deflections were approximately proportional respectively to the hysteresis of the two specimens. It formed an extremely convenient and at the same time not by any means an inaccurate method of finding the relative hysteresis of various specimens. If the instrument were supplied with standard specimens, the hysteresis of which had been already determined by the ballistic method, it was easy to find the absolute values for any other specimens that might be tested by the instrument itself. The other apparatus also proceeded on the principle of comparing the piece to be tested with a standard piece, the quality of which had been determined once for all by the instrument maker. In both the instruments his intention had been to lay the onus of absolute measurement as far as possible upon the back of the instrument maker, and to leave the observer who used the instrument nothing more to do than to make a simple comparison between the bar or strip which he had to test and the standard piece which he received along with a certificate when the instrument was supplied to him. Assuming there were two bars of iron the permeability of one of which was to be measured while the permeability of the other had been fully determined beforehand by the ballistic method or in any other way, if the two bars were connected by a pair of yokes, and both magnetizing coils with the same number of turns, then when the same current was passed through both coils, if the bars had the same quality it would follow that there was a complete magnetic circuit, that the same number of lines of induction would go up one bar as came back along the other, and consequently the two yokes would be of the same magnetic potential. If, therefore, he connected the two yokes by another piece of iron, there would be no tendency to the development of magnetism in it. But if the two bars were not of the same quality, that condition of equilibrium would no longer hold; but it might be produced by varying the number of ampere-turns upon the one bar while that at the other bar was retained constant. That was the principle on which the machine was designed. The instrument on the table, *Fig. 1*, p. 247, was a slightly altered and improved version of the one described in the Paper. In particular the yokes were of simpler form. The two bars were put into a pair of short iron blocks forming the yokes, and were clamped by a set-screw at

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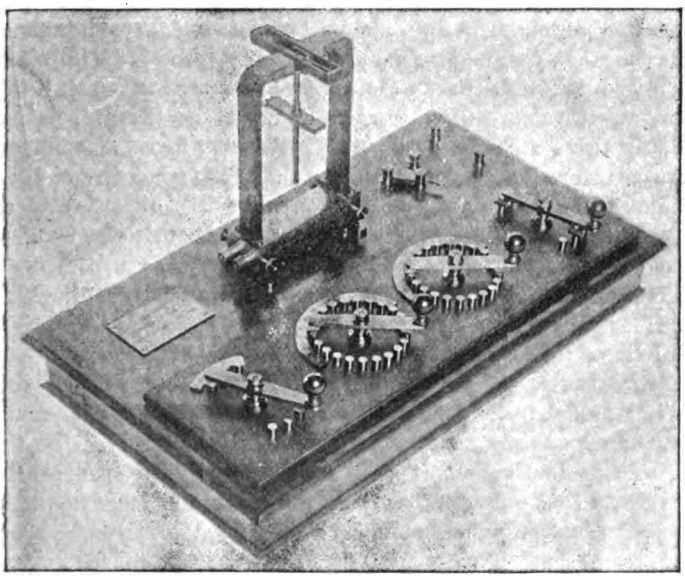
each end. On one of the bars there was a magnetizing coil of a constant number of one hundred turns, on the other bar there was a magnetizing coil, the number of effective turns in which was varied by means of revolving switches, one switch determining hundreds of turns, another tens, and another units. It was simply necessary to vary the number of turns in this coil while the same current passed through it, and also through the coil on the other bar, until the condition of equilibrium could be produced. The condition of equilibrium was shown in the following way. Prof. Ewing.

*Fig. 1.*



Permeability Bridge.

From the two yokes two soft-iron horns projected. A gap between them was filled by a box which contained a compass-needle. If there was any magnetism whatever in the horns, it would show itself by tending to deflect the compass-needle. By means of a key the current was reversed. If a condition of equilibrium existed, the reversal of the current would not show itself upon the compass-needle, and the condition of equilibrium was produced by turning the switches round until the reversal of the key showed no effect upon the compass-needle. When that condition was secured, whatever the number of turns on the bar

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Prof. Ewing. under test was, that number relatively to one hundred expressed the ratio of the magnetizing force on the test-bar to the magnetizing forces on the standard bar, which was required to produce the same magnetic induction in both. If, therefore, the magnetic quality of the standard bar had been fully determined beforehand, that observation completely and absolutely indicated the magnetic quality of the bar which was under test. The same process was repeated at a series of points on the magnetizing curve, the current being increased step by step. The instrument was designed so as to save as nearly as possible the application of arithmetic. The length between the yokes was $4\pi$ centimetres, consequently an inconvenient constant which came into the calculation of magnetic force was dispensed with. The distance being $4\pi$ centimetres, it followed that the magnetizing force upon the standard bar was simply equal to ten times the number of amperes of current. That force was therefore directly read by means of the ampere-meter outside the instrument. Having used the instrument for some months before making it public he had found that it not merely produced effective tests in a much more expeditious way than was possible by the ballistic method, but that it was capable of a degree of accuracy which was quite comparable to the highest degree of accuracy of which the ballistic method itself was capable; and he said that with some knowledge of what the ballistic method could accomplish.

Mr. Parshall. Mr. PARSHALL said that an objection had been raised to his having used in the Paper the inch as the unit of length and the square inch as the unit of area. Previous to bringing the Paper before the Institution in its present form,[1] he had carefully considered that question. Designers, so far as he had been able to ascertain, invariably used the inch and he had accordingly adopted that form; but if it was generally objected to by technical members, he would, if desired, give the curves expressing the results in centimetres.

Dr. Fleming. Dr. J. A. FLEMING remarked that the subject of testing iron was becoming an increasingly important one. He had recently had occasion to collect some statistics which pointed the moral to that effect. At the end of 1895 there were forty-seven alternating-current electric-lighting stations in England, having connected with them about 1,100,000 lamps. An approximate estimate

[1] In the Paper as originally printed Mr. Parshall's results were expressed in British measures.—Sec. Inst. C.E.

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showed that that must mean the utilization of between 50,000 HP. and 60,000 HP. of transformers, and the amount of iron in the cores of those transformers would be something exceeding 400 tons. That iron had to be magnetized a hundred times a second the whole year round, and the estimate of the power required to do that showed that it needed an expenditure of about 1,600,000 Board of Trade units per annum. Translating that into coal it meant not a small matter. From the point of view, therefore, of the user and the manufacturer, the testing of iron was becoming more and more necessary. At the end of the Paper Mr. Parshall had wisely emphasized the necessity for the manufacturer testing his products in order to know what he was using. Dr. Fleming would also venture to emphasize the necessity for the purchaser testing what he bought in order to know that he procured what he bargained for. At the present moment that, he thought, was not a usual thing to do. He was surprised to find how comparatively few engineers were in the habit of issuing strict specifications for transformers and requiring uniformity with them by exact test. Even in the cases where specifications were issued and manufacturers had to work to them they sometimes fell far short in the finished product of that which they undertook. A case occurred to him in connection with a specification which he had recently issued for a municipal corporation. The specification was for two 30-kilowatt transformers, and one clause of the specification required that the core losses at no load should not exceed the very moderate figure of 500 watts. The transformers were sent in by the firm that accepted the specification, and after giving them a little time to settle down to work they were tested. One of them was found to take up 560 watts and the other 1,090 watts at no load. If in the second transformer no tests had been made, if it had simply been taken for granted that the transformer complied with the specification, it would have meant that it was wasting at least 2,000 more Board of Trade units per annum in magnetization than the specification required. Other instances might be given. One important corporation in the United Kingdom had prepared an elaborate specification for transformers, the only thing omitted being the core loss at no load, so that manufacturers and contractors had an exceedingly free hand in dealing with the specification. The result was, that a large number of transformers took up about three times as much as they really ought to do. Another point which Mr. Parshall had dealt with, was the very important one of the ageing of iron. It was only in recent years that attention had

Dr. Fleming.

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Dr. Fleming. been drawn to the fact that not only the hysteresis and the eddy-current loss in transformer iron, but also the rate at which these changed under use must be studied. Much discussion had taken place as to its cause. The interesting Table in Appendix II of Mr. Parshall's Paper showed that that increase did not by any means always take place. It gave a number of instances of annealed and unannealed iron which, after being used magnetically for a certain time, in some cases did not increase in the hysteresis loss, while in other cases there was an increase amounting to 30 per cent. That entirely agreed with his own experience. Some time ago he had put two large transformers to work on a circuit of the City of London Electric Lighting Company. Those transformers were perfectly new, being taken as they came from the manufacturers. The core loss was measured day by day and week by week for three months, and a record was kept. After the first diminution as the transformers heated, that core loss remained constant the whole time. At the end of the three months, by which time the transformers had become very warm, there was no appreciable increase in the loss. That was not always the case. He had had an instance before him a little time ago in which the core loss of the transformer in a comparatively short time increased to three times the amount that it had when the transformer was new. The subject therefore was one which demanded serious consideration with a view of ascertaining the causes and providing a remedy. The matter was comparable with that of incandescent lamps. A few years ago the value of a lamp was appraised by its watts per candle-power. But the degradation of a lamp was a very important matter which had to be considered in making a valuation of it for commercial purposes. It was exactly the same with iron. It was not simply sufficient to state that the hysteresis loss in iron had a certain value; it was necessary to know at what rate it would change when it was used for industrial purposes. It was a matter which had not yet been exhausted, and the only way in which it would be explained was by sufficiently careful tests. Probably one of the reasons why central-station engineers had not paid more attention to transformer testing in practice, and issued strict specifications, was that they thought there might be some difficulty in applying methods of measurement. Engineers had naturally a dislike of physical laboratory methods. There were, however, methods now perfectly well understood, some of which he himself had devised, by which tests of transformers could be carried on *in sitû* in sub-stations, or in stations where

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they were placed, and where the core loss could be accurately registered from time to time. In some of the stations with which he was connected those figures were constantly taken. In a transformer sub-station where there were a number of transformers at work, if it was found that one was increasing at a rapid rate, or had a particularly large loss, it was easy to arrange that that transformer should not be made the master transformer. In some cases he had found that, owing to the ignorance of the performances of transformers, that transformer was selected for most use which was the very worst in the group connected with those circuits. The two points, therefore, that he desired briefly to emphasize were the necessity of testing the finished product—not merely testing the material utilized—and also of further careful tests to ascertain the nature of that process by which iron became magnetically aged. Dr. Fleming.

Dr. JOHN HOPKINSON thought the Papers were of a type most useful to the engineer. They gave data which were of general application and supplied the means of obtaining those data, a service which was of much greater value to the engineer than the mere placing before him of a precedent which he could work with in circumstances precisely similar to those with which he had to deal. The method he had used in his first experiments on magnetism, that by means of the yoke for closing the magnetic circuit of the sample operated upon, was referred to by Professor Ewing. That method was open to two objections. In the first place a correction was required for the ends of the bar experimented upon. He would point out that that correction was necessarily a small one, provided that the diameter of the bar was small in comparison with its length. Suppose, for example, that the length of the bar between two points of the yoke was 10 inches, and the diameter $\frac{1}{2}$ inch; the diameter then in comparison with the length was 1 in 20, or 5 per cent. It was clearly possible to ascertain the correction within a small fraction of that $\frac{1}{2}$ inch, and consequently the magnetizing force could be ascertained to a fraction of a small percentage of the whole length. The other objection was with regard to the division in the bar which he employed in the experiments. He agreed with Professor Ewing that if at the present day experiments of that character were tried that gap would not be introduced, but an entire and complete bar, and a somewhat different method used. In later experiments he had given up the method of the yoke and used a simple ring. The reason of that was not any dissatisfaction with the earlier methods, but the fact that a sample was obtained Dr. John Hopkinson.

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Dr. John Hopkinson.

in a convenient form for placing in a furnace and for making tests at a high temperature, the purpose being to ascertain the magnetic properties of the iron when the temperature was considerably raised. The properties of iron which Professor Ewing had examined mainly related to two points, first the maximum magnetism the iron was capable of and its permeability, and the second the losses due to hysteresis in its reversal. It was interesting to remark that if it were convenient to work with iron at a very high temperature, a material would be obtained which, for the latter quality was far superior to any known iron at ordinary temperatures. The hysteresis losses of ordinary iron, working at a temperature of about 700° C., were enormously less than similar losses at ordinary temperatures, but the maximum magnetization was very much less. The magnetic properties of chrome- and tungsten-steel were interesting from a different point of view from that of the properties to which the two Papers more particularly related. Their most striking quality was that the coercive force was so large in both, and consequently they would both be peculiarly suited to the making of permanent magnets. Indeed the best permanent magnets contained a very considerable quantity of tungsten, and almost equally good permanent magnets could be produced if chromium were substituted for tungsten. It was not simply that the permeability was low, but it was due to the circumstance that the permeability was low owing to the coercive force being great. The maximum magnetization of both materials was fairly high. The interesting properties of nickel steel were also referred to by Mr. Parshall, who had particularly pointed out that in the case of nickel steel containing 5 per cent. of nickel, magnetization was greater than would be inferred from the consideration of the material as a mixture of iron and nickel. The same applied in perhaps even greater degree to a mixture in which there was 73 per cent. or 75 per cent. of the nickel, and the remainder iron. In that case a very much greater maximum magnetization was obtained than would be inferred from calculating its properties from a mixture of iron and nickel, arranging the molecules in any possible way. It was evident that the two materials reacted upon each other, and gave in that case a greater effect than would be expected. Material containing 5 per cent. of nickel had been found of considerable use in the case of machines erected at Niagara. In that case it was necessary to obtain a material having a very high tensile strength and a very high maximum magnetization; and it was found that no material

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was so good for that purpose as steel containing 5 per cent. of nickel. But still more remarkable than the properties of nickel steel with a comparatively small percentage of nickel, or a very large percentage of nickel, were the properties of nickel steel containing an intermediate percentage, such as 20 per cent. or 25 per cent. Such a material revealed properties which were only met with in a much less degree, in the case of other forms of steel. As such nickel steel was delivered from the manufactory it was found practically non-magnetic, almost as non-magnetizable as manganese steel. It appeared that it was a material which could not be rendered magnetic, and which presented none of the marked peculiar characters of nickel or iron with regard to magnetism. But if a sample of this material were cooled to − 20° C. or − 30° C., or, better even, to a lower temperature, it would be found that it presently became strongly magnetizable. But that was not all. If the material were allowed to become warm again it remained magnetizable, and it continued to be so until it was heated to about 600° C. or 700° C.; when it attained that temperature it changed over again and became non-magnetizable, and when it cooled it remained non-magnetizable at the ordinary temperature. This material then could exist at the ordinary temperature in two completely distinct forms, in one of which it was almost like ordinary copper or aluminium or any other metal, and in the other it more nearly approximated to magnetizable metals such as iron and nickel. But many of its other physical properties were changed. In its non-magnetizable condition its electric resistance was totally different from what it was in its magnetizable condition; the two conditions differing by about 40 per cent. in regard to electrical resistance. The tensile strength also greatly changed. In the non-magnetizable state the breaking stress required upon the sample would be perhaps 50 tons to the square inch. When it was cooled it was rendered magnetizable and the tensile strength increased to 80 tons per square inch. The extension in the one case might be 30 per cent. and in the other it fell to 7 per cent. or 8 per cent. Finally, the density in the non-magnetizable state differed by about 2 per cent. from the magnetizable condition. Those facts might appear at the present time to be of not very great interest to the engineer, though they might be of considerable interest to the physicist. It was, however, quite possible that the time was not far distant when they might be important to the engineer. It might possibly be suggested—supposing the material were to be cheaper than it was at

Dr. John Hopkinson.

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Dr. John Hopkinson. the present time—that ships should be built of it for the purpose of obtaining a material which would not disturb the compass. But supposing one of those ships went to the Arctic regions, the poor thing would tear itself to pieces. As soon as it cooled much below freezing-point the plates would be torn off their supports, and he was afraid that the ship would be in a much worse condition than if it had to depend upon the ordinary methods of correcting its compass. To express his results Mr. Parshall had used lines per square inch and ampere turns per inch. The amperes, as was well known, was based upon the centimetre and the gram; lines were also based upon the centimetre and the gram. Grammarians strongly objected to mixing roots from two different languages in a new composite word, and engineers would, he thought, equally object to mixing two systems of measurements in one statement of results. If Mr. Parshall proposed to gain the advantage of making use of the well-known measure in terms of amperes and of lines, he should be strongly pressed to give those measurements in terms of square centimetres. He would strongly urge upon him not only to give the measurements of length and area in terms of centimetres and square centimetres, but that he should omit the results given in the old-fashioned inch, and rely on the simple measure to which all engineers were accustomed, and which would be of interest not only in this country but in other parts of the world.

Prof. Thompson. Professor SILVANUS THOMPSON considered both the Papers had distinctly advanced knowledge with respect to the magnetizability of materials such as those used in the construction of electrical apparatus. He had great sympathy with Professor Ewing in the attempt to give workshop methods of measurement in lieu of those which would be fitly characterised as laboratory methods. It was indeed in a humble way some years ago, when endeavouring to do the same thing, that he had taken upon himself to reform Dr. Hopkinson's apparatus of the yoke, and eliminate from it the ballistic method of the coils; finding the number of magnetic lines in the test-piece by simply measuring the force required to detach it from its fellow in the interior of the apparatus. No doubt Dr. Hopkinson knew perfectly well that the force required to detach the piece might measure the magnetism, but he had preferred to rely upon the indication of the ballistic galvanometer attached to it. He was far from decrying laboratory methods when engaged in research, but for bringing the matter home to practical workmen—the foreman of the shop who was expected nowadays to have some knowledge of the magnetic properties of materials—to bring home to him the

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qualities of his material—certainly required something more simple than the arrangement of the ballistic galvanometer and the paraphernalia of the physical laboratory. He therefore welcomed Professor Ewing's instruments and hoped to see them widely used. There was obviously room for other instruments, he would not say of the same type, but of kindred types. He thought, for example, that it was a defect in Professor Ewing's exceedingly beautiful instruments for measuring hysteresis that the little piece under test was subjected only to the influence of one particular magnet and therefore did not give a complete indication as to the amount of hysteresis in the iron, for which magnets of different powers would be required. He was not quite certain that there was an entire absence of error in the method of using the instrument where the speed of the revolving test-piece was left simply to the hand of the operator. The error was not a serious one, but he thought there was some error in not having the apparatus worked at a fixed speed. When he had a specimen of iron to test for hysterosis he had found that the simplest way was to make up a small sample of it and use it as a core of choking-coil, but with that in the laboratory and with a proper ampere-meter and watt-meter, all the necessary data could be obtained very easily and with quite as great accuracy as with the small revolving instrument. Two or three points had occurred to him in the course of magnetic work which entirely confirmed those which had been emphasized more particularly by Mr. Parshall. The samples obtained of specimen iron did not by any means as a rule faithfully represent the body of the material. Even a single sheet of iron was found to differ in different parts. If a portion was taken that looked rather bluer than the rest, and was tested it would be found that it had a different hysteresis from the rest. Any small difference in the material resulting from slight differences of temperature in annealing, and from slight differences of pressure in the rolling, might have considerable influence on the magnetic properties, more particularly in regard to hysteresis. It had been remarked by Mr. Parshall that the amount of loss of energy by hysteresis appeared to be the same in what, at first sight, seemed to be two very different operations. If a piece of iron or steel were subjected to the mere reversal, or to a series of mere reversals of magnetism, first in one direction and then in the other, a certain hysteresis loss was obtained. If, instead of magnetizing backwards and forwards along a line as the specimen was turned round in the magnetic field, so that the direction of the magnetization changed continuously through the whole cycle, it was stated that

Prof. Thompson.

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Prof. Thompson. the loss was the same as in the former case. That seemed very improbable; it might be nearly true, but surely the process of reversing the magnetizing from end to end and the process of turning the magnetism round upon itself involved such great differences in molecular action that there must be a considerable difference in the two cases. None, however, so far as he knew, had been observed, and the statement of Mr. Parshall was, he believed, in accordance with fact. Further, he thought that the law discovered by Mr. Steinmetz as to the variation of hysteresis with the magnetic flux density, that the hysteresis loss for a given number of cycles per second was in proportion to the 1·6th power of the flux density could not be regarded except as a very elementary approximation, and for this simple reason: If there was any truth whatever—and he believed it to be entirely true—in Professor Ewing's exceedingly beautiful theory of molecular magnetism, there must be a superior limit to the amount of hysteresis loss, and instead of being proportional to the 1·6th power, it must when the induction was carried far enough, become simply a constant. Indeed, if he remembered rightly, Mr. Baily had found something of the kind.[1] Attention was drawn by Mr. Parshall to the physical fact that vibration diminished the area of the hysteresial loop, and it was added that the energy loss did not diminish, although the area of the hysteresial loop might diminish when the specimen was subjected to vibration. He should like to know whether that was literally confirmed. The operations of vibration on the molecular structure of bodies were generally very like those which occurred when the temperature was raised. The raising of the temperature might be to a large extent a matter of molecular vibration, and if the hysteresis disappeared at high temperatures it would be expected also that it would disappear under considerable vibration. He merely threw it out as a speculation as to what ought to be found to be the case. The moral of the two facts seemed to be that mechanical or chemical data were not to be relied on as indications of the material to be selected for the building of electrical machinery, but that purely magnetic tests should be followed.

Prof. Ayrton. Professor W. E. AYRTON was more familiar with Professor Ewing's work than with that of Mr. Parshall, especially with the methods of making magnetic tests upon iron and steel. There seemed to be a little trouble in using the apparatus for testing magnetic

[1] Report of the British Association for the Advancement of Science, 1894, p. 56; also Proceedings of the Royal Society, June, 1896.

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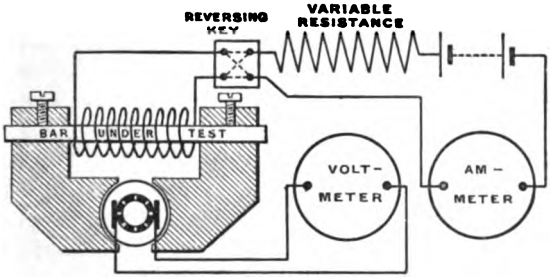
induction, which was referred to in Professor Ewing's Paper, namely, the kick the needle received due to the different times that were required for producing magnetization in the standard bar and the bar which was being tested. The test he made was very like that usual with the Wheatstone bridge in testing resistance. If, for example, the resistance of the coil round the electromagnet was required in terms of ordinary resistance coils, it was well known that if the galvanometer circuit of the Wheatstone bridge was closed before the battery circuit an inconvenient kick of the needle was experienced, which would greatly delay the taking of the reading. That difficulty was overcome by closing the battery circuit first, and then the galvanometer circuit, when, if the two resistances were equal, that inconvenient kick would be eliminated. He had thought of doing the same thing with Professor Ewing's permeability apparatus. There was a very simple way Prof. Ayrton.

*Fig. 2.*




of overcoming the difficulty; instead of using a little suspended or pivoted magnet, to replace it with a small rotating coil which might be attached to any sufficiently delicate galvanometer. The adjustment of the number of ampere-turns in the magnetizing coil could then be made by trial, as the resistances for the Wheatstone bridge would be altered. When the balance was effected, the circuit of the rotating coil was closed, and then if there was no deflection, it was known that the balance was correct. If there was a deflection the number of ampere-turns must be altered just as the resistance in the Wheatstone bridge was altered. When he had arrived at that stage it seemed that he had returned to an instrument constructed by Mr. T. Mather and himself. This instrument consisted of a small dynamo, driven at a uniform speed by an electric motor, or in any other convenient way. The specimen of iron to be tested, which might be in the form of a round bar, or a bundle of thin plates, was passed through the massive iron pole-pieces, *Fig.* 2, so as to form



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Prof. Ayrton. the yoke of the machine, and was clamped in position by screws. Through a coil, surrounding the specimen, was passed the magnetizing current, the winding being so arranged that the current in amperes, measured by the ammeter, was numerically equal either to the magnetomotive force per centimetre length of the bar, or to one-tenth of that value, depending on whether the magnetizing current was sent through a part of the coil, or through the whole coil. When the armature, which was of the Pacinotti type, revolved at a speed of 1,150 revolutions per minute, shown by a speed indicator, the induction per square centimetre of the specimen was approximately equal to 10,000 times the electromotive force generated, as measured in volts by the voltmeter. Hence not merely the magnetizing current, but also the induction was indicated by the steady deflection of an instrument, and not, as usual, deduced from the instantaneous swing of a ballistic galvanometer. When this apparatus had first been used in his laboratory the difficulty had occurred that, although the air-gap between the armature and the faces of the pole-pieces was very small, and although the joints between the ends of the specimens and the pole-pieces were good, it was necessary to subtract from the current an amount which depended on the induction in order to obtain the true magnetizing current. This could of course be obtained by calculation, but it afterwards occurred to Mr. Mather and himself that the value of this correction could most easily be deduced by using the apparatus with a standard bar, the B H curve of which had been previously obtained with the ballistic galvanometer in the same way as Professor Ewing experimented with his standard bar. And to avoid having to trouble about this correction in all future tests, it was merely necessary to have wound round the ammeter coil a small demagnetizing coil in series with the voltmeter. Any bar turned to fit the holes was then put in, and the direct induction test could be at once made. Great stress had been laid by Dr. Fleming on the importance, not only to the manufacturer but to the buyer, of testing the transformers. The difficulty, however, he at present saw was as to the conclusion to be arrived at, because it appeared that the same iron might increase its hysteresis loss by more than 300 per cent. in three years. It had been mentioned by Dr. Fleming that the iron in one transformer had a loss of 500 watts at no load and another of 1,000 watts at no load; but, unless he was sure that, in those two transformers, the irons would always bear the same ratio to one another, Professor Ayrton did not see what conclusion could be drawn. It might be that the transformer which to-day had a loss of 1,000 watts, would in three years be a better trans-

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former than the one which had only lost 500 watts. Therefore, until it was explained why some iron increased in its hysteresis loss when it was made to pass through certain cycles of magnetization it could not be foretold whether the better iron of to-day, when made up into a transformer, would be better or worse three years hence. Prof. Ayrton.

Professor EWING, in reply to the discussion, entirely agreed with Dr. Fleming as to the importance of testing the iron of transformers and as to the desirability of strict specifications in regard to hysteresis loss. There was no doubt considerable evidence that under certain conditions the iron of a transformer deteriorated with use; but an engineer should at least satisfy himself that he was not using a needlessly bad iron to begin with. Moreover it would not be difficult, in some forms of transformers, to arrange for the removal of a sample strip from the core from time to time with the object of testing whether change for the worse took place. This test could be readily made by means of his hysteresis tester, which required only a few square inches of the sheet to make up a sample. Prof. Ewing.

The correction required for the yoke when a yoke was used to close the magnetic circuit in testing the permeability of iron bars had been referred to by Dr. Hopkinson. By using the method of two bars and two yokes, as described in the Paper, the correction for the yoke was found experimentally and was completely eliminated. This was done by sliding the yoke along the bars so as to include first a longer and then a shorter length of the bars in the circuit. The device gave the method of the yoke a degree of precision it had not had before, and adapted it for exact absolute measurements. It was by this means that the magnetic quality of the primary standard bars used in his new permeability bridge had been determined. The bridge itself then served to compare any bar intended to serve as a secondary standard with the primary standard. By simply using the instrument Professor Thompson would, he believed, satisfy himself that the hysteresis tester gave indications which did not depend on the speed with which the sample was timed. For testing transformer iron it was enough to find the hysteresis loss at one value of the induction, the formula of Mr. Steinmetz being sufficiently accurate, within the range of inductions actually used in transformers, to allow the loss at other inductions to be inferred from the loss at one. It was quite true that large variations were to be observed in the hysteresis loss in iron, even within the limits of a single sheet, and attention had in fact been drawn to this in his description of the use of the hysteresis tester. He had noticed as much as 15 per cent. variation in the four corners of a plate not 2 feet square. The kick



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Prof. Ewing. referred to by Professor Ayrton, as shown by the needle of the permeability bridge when the magnetizing current was reversed, did not in practice cause any serious inconvenience, and it was sufficient to damp the oscillation of the needle by placing it in a copper ring. In developing the instrument he had considered several forms of detector, but he had found the simple compass needle at once so sensitive and so convenient that he had no wish to change it for any other.

Mr. Parshall. Mr. PARSHALL said, in reply to Dr. Hopkinson, that on p. 224 of the Paper the intensity of magnetic flux was stated to be expressed in C.G.S. lines per square inch. The effect of the nature of the reversal and the magnitude of the hysteretic loss was stated in the Paper to be the same, whether or not the iron was rotated through a magnetic field, or the magnetism was reversed as in an alternating-current transformer. There was abundant proof to show that this statement was correct within the precision with which hysteresis might be measured, and within the limits specified in the Paper. As to the hysteresis loss remaining constant for the different methods of reversal, he did not consider this to be in contradiction to the theory advanced by Professor Ewing. The molecules were reversed in direction, and the displacement in space, as in the case of a rotating disk, with respect to the source of magnetization, did not necessarily affect the interaction between the molecules. In either case they were internally reversed; indeed, the value of Professor Ewing's instrument depended upon the hysteresis being independent of the nature of reversal. Tests made by this method were found to agree with the results obtained in a rotating disk, and in an alternating-current transformer. With reference to the statement that hysteresis varied with the 1·6th power of magnetism, the limitation to which this exponential and empirical law applied, was clearly stated in the Paper, that was, within the limits with which material might be produced in practice for uniform results, and within the limits of magnetization obtaining in practice. The range in which the 1·6th power held practically good was within the magnetizations obtaining in practice, and within the limits to which it had been stated as applying to the Paper. The fact of the diminished area with the hysteretic loop under vibration was well established by experiment. In the case of armature iron, he had, in an actual test, under the same amount of vibration as took place in a generator armature, obtained a very great diminution of the area of the hysteretic loop. In an armature in which the iron was used, it was found that the hysteretic loss agreed with that predicted from

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the area of the hysteretic loop when the iron was not subject to vibration. Hysteretic loss could not perhaps be considered the proper term to apply to the loss in iron under these conditions. The general term "energy loss in iron," as used in the second part of the Paper, might be more applicable. He had made no statement with reference to the nature of any magnetic phenomena that would carry the discussion to a speculative field, involving theories as to intermolecular actions. It was his intention to make a definite statement of the results obtained by measurements, the accuracy of which had been amply and repeatedly confirmed. Mr. Parshall.

## Correspondence.

Mr. PHILIP DAWSON thought it was owing to the use of cast steel in the construction of railway-motors that efficiency, durability, and large output had been combined with comparatively light weight. In supplying the great demand in America for railway- and tramway motors and generators during the past few years, the knowledge of the materials available in their manufacture had made it possible to produce them so that their magnetic as well as their electrical powers were interchangeable, a point of the greatest importance. The large 2,000-HP. direct-coupled railway generators, a number of which had been now successfully running for over three years, introduced by Mr. Parshall as designing engineer of the General Electric Company of America, demonstrated the value of his careful study of the subject-matter of the Paper. These generators were all erected and tested in their final position, and the results obtained were practically identical with those calculated. In several parts of the apparatus inductions as high as 20,000 C.G.S. lines per square centimetre were used. It could not but be of great importance to know accurately the influence of the various chemical ingredients when it was a question of producing machines which with identical windings would give identical results and work harmoniously. Mr. Dawson.

Dr. H. DU BOIS, of Berlin, remarked that the important and valuable data given by the Authors, together with those obtained by Dr. E. Taylor Jones and himself, gave a tolerably full indication of the high position the iron and steel industry had in a few years attained in this respect on the Continent as well as in the United Kingdom. It would seem as if producers had clearly differentiated the two materials—high-permeability metal for dynamos, low-hysteresis metal for transformers—so as Dr. du Bois.

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Dr. du Bois. to meet the particular requirements of users in both branches. The former was also to be used for all kinds of "stationary" electro-magnets. Some applications, though of less commercial importance, however, remained in which both qualities were necessary; for example, yokes for experimental work, shells for iron-clad galvanometers, in which he was especially interested. He had tested his material from both points of view, his magnetic balance (described by Professor Ewing on p. 197, *ante*) being used up to fields of a few hundred C.G.S. For strong fields he had applied the well-known isthmus method. A few of the data were given in the following Table:—

| H. | B. Krupp. | B. Swedish. |
|---|---|---|
| 5 | 10,600 | 12,550 |
| 10 | 13,200 | 14,300 |
| 15 | 14,150 | 15,000 |
| 20 | 14,650 | 15,400 |
| 30 | 15,450 | 16,000 |
| 40 | 16,000 | 16,450 |
| 50 | 16,350 | 16,650 |
| 100 | 17,450 | 17,550 |
| 5,000 | 25,250 | 27,500 |
| 10,000 | 31,900 | 32,900 |
| 15,000 | 37,200 | 38,200 |
| $H_c$ | = 1·8 | 0·8 |
| U | = 12·4 | 6·6 |

As usual, H stood for magnetic force, B for induction, $H_c$ for coercive force (all in C.G.S. units), U for hysteretically dissipated energy in kilo-ergs per cycle per cubic centimetre. U and $H_c$ referred to the maximum loop, the cycle being taken between such limits that their increase would no more materially affect the size of the loops. The column headed "Krupp" referred to this firm's "Dynamo-Stahlfaçonguss," and was identical with "VI" in the Table on p. 210 of Professor Ewing's Paper. He had adduced these figures to show their surprising concordance (almost within 1 per cent.) with Professor Ewing's obtained with a ring. It might be concluded that the homogeneity of the cast material on the one hand, and the accuracy of the measuring devices on the other, were satisfactory. In the Reichsanstalt very nearly the same curves for this cast steel had been obtained by the bar-and-yoke method (p. 198, *ante*). This homogeneity and consequent uniformity of results afforded a striking contrast to the great differences ob-

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servable (even in one piece) of non-cast material. The figures in the column headed "Swedish" related to the best Swedish rolled iron obtainable. They remained below the "pure iron" of the Elswick works (I, p. 210); the coercive force and hysteresis was, however, remarkably small. In this connection Dr. Ebeling, of the Reichsanstalt, had found a coercive force of only 1·2 C.G.S. for a specimen of cast steel annealed in a porcelain furnace with the utmost precautions.[1] On the other hand, the "hardest tungsten steel" showed a coercive force of 72 C.G.S., and dissipated 265 kilo-ergs per cycle per cubic centimetre. Dr. du Bois.

Mr. F. Osmond regarded the Authors' work of as great importance to the metallurgists as to the electricians. The magnetic constants of a given metal not only concerned the engineer who employed the metal for the construction of dynamo machines and transformers; they were, up to a certain point, characteristic of the chemical composition, of the thermal or mechanical treatment, and in the end of the mechanical properties. Unhappily physics and metallurgy had too long ignored the services they could mutually render each other. Most workers in the field of magnetism considered, for example, "Swedish iron," or "Sheffield steel," sufficient designation for the materials they employed, so that it was impossible to generalise the results obtained in a particular case. The number of data necessary for defining a steel bar was considerable, particularly in the case of hardened steel, in which it was important to know:—(1) the chemical composition; (2) the previous history of the metal, or at least the microstructure, which permitted of its approximate reproduction; (3) the method of heating; (4) the rate of heating; (5) the maximum temperature of heating; (6) the temperature at the moment of quenching; (7) the dimensions of the bar; (8) the state of the surface; (9) the nature of the hardening bath; (10) the temperature of the hardening bath; (11) the weight of the hardening bath; (12) whether the hardening bath was agitated or not; (13) the temperature of emersion of the bar, if it was not the same as that of the bath. Even this list might still be incomplete. What metallurgists asked of physicists was, that they should ascertain the exact function of each of these factors in the final magnetic properties. This the Authors had perfectly realised in determining beforehand the chemical composition and the conditions of manufacture of their specimens; and the precaution greatly increased the value of their results. When the relations sought for were more Mr. Osmond.

[1] Zeitschr. f. Instrumentenkunde, vol. xvi. p. 86, 1896.

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Mr. Osmond

completely known, magnetic trials would assume considerable importance in metallurgical works. Twenty years ago Mr. Ryder, engineer to the Otis Steel Works, had proposed to classify steels by the residual magnetism of short bars,[1] and Mr. Osmond, in studying this method of classification, had found it practically in accordance with that based on tensile strength. A great advantage of these magnetic tests was that they could be applied to the finished pieces, and not merely to a test-piece more or less restricted as to shape. He could not see why the ingenious methods of Professor Ewing could not be applied, with suitable modifications, to the very pieces manufactured. It did not appear impossible, or even difficult, with a well-designed installation, to test all the rails, all the axles, or all the tires produced in any works, and, the conditions of manufacture remaining practically the same, to discard all the products which did not reach a certain prescribed standard.

Mr. Wilson.

Mr. Ernest Wilson observed that on p. 192 Professor Ewing described a convenient arrangement for the determination of curves of induction and hysteresis employing the ballistic galvanometer. In calibrating his instrument the Author made use of the absolute determination of current, but Mr. Wilson considered the Clark standard cell could be very conveniently used for the purpose of finding sensibility. He asked, with regard to the magnetic bridge, if the disturbance of the linear distribution of current-turns on the test-piece gave the same result as when the turns were kept constant and the current varied. The sample of steel-forging III (p. 210) was exceptionally good for the purpose of magnet limbs where high induction density was used, being almost equal to the very pure iron I. He had no doubt Professor Ewing had not specially chosen the hysteresis data for magnet steel given on p. 215 as being low. Experiments recently made in the Siemens laboratory on a ring of this steel had given the following results, which were considerably lower than those given in Professor Ewing's Paper :—

| | | | | | | |
|---|---|---|---|---|---|---|
| Limits of Induction per Square Centimetre, B . | 2,000 | 4,000 | 6,000 | 8,000 | 9,000 | 10,000 |
| Dissipation of Energy by Magnetic Hysteresis in Ergs per Cubic Centimetre per Cycle . . . | 350 | 1,000 | 2,050 | 3,400 | 4,300 | 5,300 |

[1] *Engineering and Mining Journal*, January 13 and March 31, 1877.

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Mr. Wilson. With regard to Mr. Parshall's Paper, the investigations mentioned on p. 233 were of great interest. He had been engaged a short time ago on research to find if the rate at which energy was dissipated by magnetic hysteresis for a given frequency and for a given maximum induction per square centimetre was different when the same specimen was subjected to first, an alternating magnetic field, and secondly, to a uniform rotating field of constant intensity.[1] He was not aware that the dissipation of energy in the two cases had been demonstrated to be the same. He asked if the effect of induced currents had been eliminated in the curves shown in *Fig. 21*, as this was not warranted by the mere fact of the armature-core being smooth.

Dr. Veillon. Dr. Henri Veillon, of Basle, had devoted a considerable time to the investigation of the magnetization of steel by the oscillatory discharge of the Leyden jar, and had embodied the results of his experiments in two Papers[2] which he thought would be found useful to those interested in the subject.

Prof. Ewing. Professor Ewing, in reply to the Correspondence, regarded the additional data contributed by Dr. du Bois to be valuable, especially as affording an example of iron exceptionally free from hysteresis. The Swedish iron quoted by Dr. du Bois had a lower coercive force than any sample he had ever tested, and low coercive force was associated with low hysteresis. On the other hand, it was interesting to notice that the permeability of the material under comparatively strong magnetizing force was considerably short of the permeability he had found in many examples of steel casting. The exceptionally low hysteresis of the Swedish sample was in agreement with what he had himself remarked, that the best transformer plates were rolled from Swedish iron. Why this iron should be so destitute of hysteresis was a question to which the results of analysis could not be said to furnish the answer. Mr. Osmond's suggestion that magnetic tests might come to be used as a guide to the mechanical qualities of steel opened up a large question, that of the relation of the magnetic to the general mechanical qualities of the material. He doubted whether there was any sufficiently simple and invariable connection between mechanical

[1] Report of the British Association for the Advancement of Science, 1894, p. 576.

[2] "Sur l'aimantation de l'acier par les décharges oscillantes de la bouteille de Leyde." Archives des Sciences Physiques et Naturelles, Geneva, vol. xxxiv. October, 1895; and "Über die Magnetisierung des Stahles durch die oscillatorische Entladung der Leydener Flasche." Verhandlungen der Naturforschenden Gesellschaft in Basel, vol. xi. part 2. Copies of these essays are placed in the Library.—Sec. Inst. C.E.

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Prof. Ewing. and magnetic qualities to allow one to serve as an index to the other. The steel castings now so largely used for dynamos were not easily distinguishable from good forged iron in their magnetic qualities, but when tested mechanically they had nothing in common with forged iron. A more promising field of inquiry in this connection appeared to him to be opened up by the researches of Mr. Osmond and others into the microstructure of iron. It was impossible to look at the beautiful micro-photographs of steel sections, in the taking of which Mr. Osmond was a pioneer, without feeling that microscopic examination undertaken alongside of magnetic examination might yield important results.

In reply to Mr. Wilson's question, it was the case that any such variation in the linear distribution of current-turns as occurred in the use of the permeability bridge did not give rise to inconvenience or inaccuracy. The turns were so arranged in the winding of the coils as to make this variation comparatively small. When a state of balance had been reached with say 100 turns in a single coil, the switches could be shifted so that the same number of turns was made up by other coils, namely by the tens and units, and the balance still remained good. Similarly ten one-turn coils could be substituted for any one of the ten-turn coils without disturbing the balance. Tests of this kind show that the coils, as arranged, had practically the same effect per turn no matter what was their distribution over the bar. The sample of dynamo-magnet steel for which hysteresis data were given on p. 215 of the Paper had not been selected as having specially little hysteresis, but only as being an example for which the Author had particularly complete data. In point of fact it had more hysteresis than most samples of dynamo casting, and much more than some samples. The question whether hysteresis had the same value in a reversed field as in a rotating field had been made the subject of a recent communication by Mr. F. G. Baily to the Royal Society. He found more hysteresis in the rotating field, until the induction was raised to a high value. Then the hysteresis in the rotating field began to diminish, and under stronger inductions it continued to diminish until almost all trace of hysteresis disappeared. This result was in striking confirmation of Professor Ewing's theory of the molecular process in magnetic induction, which ascribed the stability of the molecular magnets to the mutual forces they exerted on one another in consequence of their magnetic polarity, and explained hysteresis as the dissipation of energy involved in breaking up stable conformations of molecules.

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Mr. PARSHALL, in reply to the Correspondence, considered that a sufficient number of measurements were embodied in the Paper to prove the accuracy of the statement, that, "within the limits assumed, the hysteresis loss remained the same, whether the magnetism rotated through the field, as in the case of a dynamo, or was simply reversed, as in the case of an alternating current transformer." He was aware of the results of Mr. Baily and others, showing that for very high magnetizations, outside of the field discussed in the Paper, the statements did not hold good. The limitation as to the correctness of the statements, was, however, definitely stated at the beginning of the discussion on "Hysteresis"—that was, within the limits of the magnetization obtaining in practice and those within which such material could be produced to give uniform results. Beyond these limits it was not the purpose of the Paper to discuss. As to the effect of induced currents, it was generally known that in the air-gap armatures with projections offered a variable magnetic reluctance, and currents were therefore induced in the pole-pieces; for this reason the tests were made, as stated, upon smooth core armatures. The armatures were in each case concentric with axes of rotation, so that there was no variation of magnetic reluctance, and consequently no induced currents in the pole-pieces. The disks of the armature were carefully laminated from each other, so that parasitic currents in the body of the core were avoided. The error due to Foucault currents from the appreciable thickness of the plates was negligible. An analysis of the curves would show that there was no indication of the loss increasing with the square of the magnetic intensity which was sufficient indication that there was no appreciable error brought about by electrical losses. Mr. Parshall.

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## ANNUAL GENERAL MEETING.

2 June, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 28th of May, 1895, which the President was authorized to sign.

It was moved by the President, seconded by Mr. J. Wolfe Barry, C.B., F.R.S., the senior Vice-President, and resolved by acclamation,—That the members of The Institution of Civil Engineers desire to convey their special congratulations to their esteemed and distinguished Honorary Member and Past Member of Council, The Right Hon. Lord Kelvin, on the occasion of the Jubilee of his Professorship of Natural Philosophy in the University of Glasgow, and to record their high appreciation of the pre-eminent and life-long services he has rendered in promoting the object for which, according to the Charter of 1828, the Institution itself was founded, namely, "The acquisition of that species of knowledge which constitutes the profession of a Civil Engineer, being the art of directing the Great Sources of Power in Nature for the use and convenience of Man."

The Report of the Council upon the Proceedings of the Institution during the Session 1895–96 was read, with an abstract of the Statement of Accounts.

After consideration it was resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings."

The Scrutineers then reported the election of:—

*President.*

JOHN WOLFE BARRY, C.B., F.R.S.

*Vice-Presidents.*

William Henry Preece, C.B., F.R.S.
Sir Douglas Fox.
James Mansergh.
William Anderson, C.B., D.C.L., F.R.S.

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*Other Members of Council.*

Alexander Richardson Binnie.
Henry Deane, M.A.
William Robert Galbraith.
George Graham.
James Henry Greathead.
J. C. Hawkshaw, M.A.
Charles Hawksley.
John Hopkinson, Jun., M.A., D.Sc., Wh.Sc., F.R.S.
Alexander Blackie William Kennedy, LL.D., F.R.S.
John Kennedy.
George Fosbery Lyster.
Sir Guilford L. Molesworth, K.C.I.E.
Captain Sir Andrew Noble, K.C.B., F.R.S., late R.A.
William Shelford.
Bindon Blood Stoney, LL.D., F.R.S.
Francis William Webb.
Sir William Henry White, K.C.B., LL.D., F.R.S.
Sir Edward Leader Williams.

Resolved,—That the thanks of the meeting be given to the Scrutineers, that they be requested to furnish to the Council the numbers of the votes recorded for the elected Council, and for the ten members next following for whom votes had been recorded, and that the Ballot-Papers be destroyed.

Resolved,—That Messrs. Arthur Cameron Hurtzig and John George Griffiths be appointed Auditors for the ensuing year; and that the thanks of the Institution be tendered to Messrs. W. T. Douglass and A. C. Hurtzig for the time and trouble bestowed by them in auditing the Accounts for the past financial year.

Mr. Douglass acknowledged the Resolution.

Resolved,—That the thanks of the Institution be tendered to the Vice-Presidents and other Members of Council for the assistance they had rendered in promoting its objects.

Mr. J. Wolfe Barry replied on his own behalf and that of his colleagues.

Resolved,—That the members present at this meeting desire, on behalf of themselves and others, to place on record their high appreciation of the services rendered to the Institution by Sir Benjamin Baker, President, during his year of office.

Sir Benjamin Baker having replied, the Meeting ended.

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## REPORT OF THE COUNCIL, SESSION 1895–96.

IN reporting to this Annual Meeting upon the present condition of the Institution, it is important in the first place to notice the changes that have been effected during the past Session in the Charter and the By-Laws.

The question of the constitution and the mode of election of the Council has received careful attention from successive Councils since 1888, when reference was made to it in the Annual Report, and their predecessors also had considered on many previous occasions the expediency of providing for a more rapid circulation through the Council. Thus as long ago as 1854, in response to a request from the members, a special meeting was convened at which were discussed proposals for "(1) A more popular mode of electing the Council; (2) The infusion of new blood into its constitution; (3) The retirement of four of the Members of Council every second year; and (4) The addition to the Council of three non-resident members." The Council expressed the opinion then, as on subsequent occasions when questions involving similar principles were raised, that "it was undesirable under existing circumstances to effect any material changes in the mode of constituting the representative body of the Institution." In 1854 the number of Members and Associates was 726 as compared with 6,030 at the present time. Other conditions too have changed greatly in the past forty-two years, and the Council which now goes out of office has been of opinion that the existing circumstances were such as to render changes in the constitution and the mode of election of the Council desirable in the interests of the Institution. That view having been ascertained to be cordially concurred in by the members generally, the Council did not hesitate to recommend that a Supplemental Charter should be applied for, in order that the desired alterations might be effected. At a Special General Meeting held on the 6th of February last[1] a petition to Her Majesty, prepared by the Council with the assistance of its legal advisers, was duly

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 202.

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adopted, and a new Supplemental Charter was granted on the 20th of March. At a Special General Meeting held on the 15th of April[1] the By-Laws were altered so as to bring them into conformity with the powers thus obtained. Under the new Charter the members of the Institution are at liberty to fix the number of the Council by the By-Laws from time to time, thus admitting of the full and proper representation of all engineering interests both at home and in the Colonies and India. The broad principle thus embodied in the constitution has aroused interest and attention in many quarters. The Right Hon. James Bryce, M.P., late President of the Board of Trade, on a recent occasion remarked in this connection :—"It is with the heartiest sympathy that those of us who watch the efforts that are being made in the political sphere to bring the Colonies closer to their mother-country welcome such a step as you are taking, which will unquestionably give you a firmer hold on the members of your profession beyond the seas." Further, the Corporate Members are given the power of voting for the election of the Council without the necessity of attending the Annual General Meetings—a condition which before practically debarred the vast majority of the members from exercising their privileges in the foregoing respect.

In framing the balloting list for the election of its successors, the Council, in accordance with the powers conferred by the By-Laws, fixed the number to be elected for the session 1896–97 at 23, including the President and the four Vice-Presidents. This is an increase of three in the number of the Council, and, as the President did not wish to be nominated for a second year of office and Sir Edward J. Reed, K.C.B., had retired, at least five new Members of Council have to be elected. The list contains, in accordance with the By-Laws, the names of 7 Corporate Members who have not served upon the Council during the current or the preceding year. In selecting these names consideration has been given to the nomination of members representative of the Colonies and of the Indian Empire as well as of different parts of the United Kingdom.

## The Roll.

The additions to the roll during the year ending the 31st of March, 1896, numbered 290, while by death, resignation and erasure 181 names disappeared from the list. The net increase was, therefore, 109, the total number of members on the 31st of March,

[1] *Ante*, p. 126.

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1896, being 6,030, as against 5,921 on the corresponding date last year.

| | April 2, 1894, to March 30, 1895. | | | | | April 1, 1895, to March 31, 1896. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Honorary Members. | Members. | Associate Members. | Associates. | Totals. | Honorary Members. | Members. | Associate Members. | Associates. | Totals. |
| Numbers at commencement | 20 | 1,832 | 3,557 | 357 | 5,766 | 17 | 1,862 | 3,687 | 355 | 5,921 |
| Transferred to Members | .. | 58 | 58 | .. | | .. | 57 | 55 | 2 | |
| Elections | .. | 29 | 286 | 5 | 325 | 3 | 27 | 244 | 9 | 290 |
| Restored to Register | .. | 2 | 3 | .. | | .. | 1 | 6 | 0 | |
| Elected Honorary Member | .. | .. | .. | .. | | .. | .. | 1 | .. | |
| Deaths | 3 | 47 | 36 | 3 | 170 | .. | 40 | 35 | 17 | 181 |
| Resignations | .. | 6 | 26 | 2 | | .. | 10 | 21 | 6 | |
| Erased | .. | 6 | 39 | 2 | 155 | .. | 13 | 37 | 1 | 109 |
| Numbers at termination | 17 | 1,862 | 3,687 | 355 | 5,921 | 20 | 1,884 | 3,788 | 338 | 6,030 |

Among the deceases recorded will be observed several of members whose connection with the Institution formed notable links between its earlier and its more recent history. Of these Mr. James Abernethy, Past-President, joined the society in the year 1844; whilst Sir Macdonald Stephenson had at the time of his death been on the books as a Corporate Member for sixty years. Other well-known names which appear here are Peter Denny and Daniel Kinnear Clark, familiar to two generations of engineers.

The deceases have been:

*Members.*—Harold William Abernethy; James Abernethy (*Past-President*); Edmund Scott Barber; Humphrey Chamberlain; Jabez Church; Daniel Kinnear Clark; William John Bird Clerke, B.A., C.I.E.; Alfred Collett; William Crabtree; John Henry Davis; Peter Denny, LL.D.; Richard Elihu Dickinson; William Alfred Eckersley; Alexander Fraser; Alfred Fraser; Thomas Howard; William Kilvington; John Lawson; Harry Corbyn Levinge, B.A.; *Commodore* Ferdinand Wilhelm Weghorst Lüders; Philip Henry MacAdam; James Adair McConnochie; James McRitchie; Thomas William Miles; Joseph Mitchell; John Muirhead; William Nethersole; James Crawford Park; James Price, M.A.I.; Charles Richardson; George Robertson; Owen Charles Dalhousie Ross; David Simms; Douglas Ansthwaite Stanley; Patrick Stirling; Ralph Hart Tweddell; William Wainwright; George Ambrose Wallis; Arthur Mellen Wellington; and John Young.

*Associate Members.*—James Smyth Benest; William Binns; John Douglas Ormond Bridges; Lindsay Burnet; Alfred Thomas Cooke; Fitzherbert Ruxton Despard; William Henry Grahame; Harry Jones Harman; Richard Frederic Fitz-Edmund Hayes, M.A.; Herbert Edgell Hunt; Edward Wilthew Jackson;

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Mathew Buchan Jamieson; Edward Worrell Jarvis; Frederick Jorgensen; Joseph Godber Knighton; James Henry Cornwall Langdon; Richard Aloysius Lavertine, B.E.; John Benjamin McCrea; Louis Martineau; Radhica Prosaud Mookerjee; James Abbott Oxley; Alfredo Henrique Pacheco; Charles Edward Peake; John Sinclair Pirrie; William Pollock; Frederick Charles Preston; Lancelot George Prickett, F.C.H.; Edward Quick; Frederick Henry Smiles; Charles Leopol Strapp; John Percy Stuart; Michael Nicholson Thomson; Robert William Lyons Toozs; Frederick Howard Watson, B.A.; and Thomas Samuel Weeks.

*Associates.*—William Alexander Adams; George Parker Bidder, M.A., Q.C.; *Colonel* Francis David Millett Brown, V.C.; Richard Carter; David Chadwick; John Clutton; *Colonel* Lewis Conway-Gordon, C.I.E., *late* R.E.; Joseph Glass Cowley; John Henry Greener; John Thewlis Johnson; Charles Thomas Lucas; Adalbert Morawski; John Henderson Porter; Charles Schafhaentl, M.D.; *Sir* Rowland Macdonald Stephenson; *Major-General* Richard Hugh Stotherd, C B., *late* R.E.; and George Harlowe Sumner.

The following resignations have been accepted:—

*Members.*—George Miller Cunningham; John Dempster Ferguson; Edward Filliter; Robert Edward Forrest; Daniel Pryce; *Sir* James Ramsden; Alfred Roberts; Ernest Alfred Sibold; Gerald Edward Smith; and Thomas Finsbury Septimus Wakley.

*Associate Members.*—William Wingfield Bonnyn; Joseph John Browne; Arthur Carey; William Henry Clemmey; Alexander Downie; James Alexander Cameron Hay; James Allan Henderson; Charles Louis Hett; Samuel Hornidge; Eugene John Charles Keelan; Emile Jean Rodolphe Kern; Kochuthommen Kuruvila, B.C.E.; Thomas William Large; William Mercer; Hugh Mitchell; Frank Charles Powell; João Duarte Lisboa Serra; William Acheson Traill; Alfred Authorn Wickenden; Charles Wood; and John Thomas Wynne.

*Associates.*—*Lt.-Col.* William Henry Beckett; Robert Neville Grenville; James Hart; *Sir* Charles Mark Palmer, *Bart.*, M.P.; George Pullin Pocock; and James Rock.

## Admission of Students.

The rate of admission to the Student Class during the twelve months under review has been well maintained, as may be seen from the Table appended. The total on the 31st of March, 1896,

Students.

| 1894–95. | | | 1895–96. | | |
|---|---|---|---|---|---|
| April 1, 1894 | | 791 | April 1, 1895 | | 816 |
| Admitted during the year | 212 | | Admitted during the year | 215 | |
| Restored to List | 1 | | Restored to List | 1 | |
| | 213 | | | 216 | |
| Elected Associate Members | 94 | | Elected Associate Members | 58 | |
| Resigned | 14 | | Resigned | 17 | |
| Deceased | 2 | | Deceased | 3 | |
| Erased | 78 | | Erased | 77 | |
| | 188 | | | 155 | |
| | | 25 | | | 61 |
| March 31, 1895 | | 816 | March 31, 1896 | | 877 |



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was 877, against 816 at the corresponding period of last year. The regulations as to the preliminary education of intending Students have been by degrees more stringently enforced as the rules were deemed to have become more generally known; and it is found that upwards of 80 per cent. of the applicants for admission have satisfied the requirements of the Council in each of the last two years.

## Finance.

The Statement of Accounts (see p. 278), duly signed by the Auditors, contains as its largest item that for the new building and cannot therefore be compared with those of previous years.

During the year the following amounts were received:—Income, £21,778 17*s.* 3*d.*, of which £17,847 14*s.* 6*d.* represented subscriptions, £1,705 19*s.* 5*d.* miscellaneous items, and £2,225 3*s.* 4*d.* dividends; Capital, £24,359 2*s.*, of which £20,690 18*s.* 6*d.* was derived from the sale of stocks to meet expenditure on the new building; and Trust-Funds account, £474 15*s.* 8*d.*, making a total of £46,612 14*s.* 11*d.* The expenditure amounted to £53,334 0*s.* 11*d.*, allocated as follows: — Income, £17,074 7*s.* 9*d.*, including £9,061 13*s.* 1*d.* for publications; Capital, £35,935 12*s.* 2*d.*, of which £34,205 12*s.* has been absorbed directly by the new building, while the remainder represents incidental expenditure incurred in connection therewith; and Trust-Funds account, £324 1*s.* With regard to the amount expended on the new building during the current year, it may be interesting to note that it has been derived as follows: Sale of stocks, £20,690 18*s.* 6*d.*; Fees and Life Compositions received during the year, £3,668 3*s.* 6*d.*; excess of receipts over expenditure, £4,855 4*s.* 2*d.*; while the remainder, £6,721 6*s.*, has been drawn from the balance in hand at the beginning of the year.

The summary printed at the end of the Abstract of Receipts and Expenditure shows Institution investments of a nominal value of £54,000, and funds held in trust £16,987 2*s.* 4*d.* £40,000 represents the cost of the freeholds with the buildings that formerly stood on them, and the nominal value of the Whitworth legacy is £5,400.

## Session and Meetings.

The measures referred to at the end of the last Report, and the efforts of the Architect and Contractors, enabled the Council to hold the first meeting of the Session in the new building on the prescribed day, when the President delivered an Address to a

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very large audience—598 names being actually recorded in the attendance-book. In addition to that gathering there have been twenty-three Ordinary Meetings at which nineteen Communications have been read and discussed. The subjects treated cover a range as wide as that comprised in Tredgold's well-known definition of the art of the Civil Engineer.

Referring to engineering operations—the means of transport in great cities are illustrated by Mr. Greathead's Paper on "The City and South London Railway." The supply of water is dealt with in the descriptions of the "Thirlmere Works," by Mr. Hill, and the "Vyrnwy Works," by Mr. Deacon; whilst both that question and the drainage of vast centres of population are illustrated by Mr. Parsons' memoir on "The Municipal Works of Buenos Ayres." Dr. Corthell's account of the "Tampico Harbour Works" refers to a branch of engineering which facilitates maritime commerce and develops it in the face of natural obstacles. The construction and adaptation of machinery is represented by Messrs. Heenan and Gilbert's Paper on "Centrifugal Fans," by "The Manufacture of Steel Plates" described by Mr. Head, by Mr. Wellman's account of "American Rolling-Mills," and by Mr. Clerk's statement of "Recent Developments in Gas-Engines." Examples of the application of electric energy to commercial and industrial uses are afforded by Mr. Cuningham's notice of the "Montreal Electric Tramways," and that of the "Extraction of Aluminium by Electrolysis," given by Mr. Hunt. Mining and metallurgy are dealt with in Papers on "The Lixiviation of Silver Ores," "The Tharsis Copper Mines," and "The Extraction of Tin," by Messrs. Clemes, Courtney, and McKillop and Ellis respectively.

In another not less important category are Papers of a highly scientific character—Captain Sankey's review of "The Thermal Efficiency of Steam-Engines"; Prof. Arnold's investigation of "The Influence of Carbon on Iron"; Mr. Wrightson's examination of "The Dilatation, Annealing and Welding of Iron and Steel," and the memoirs on the Magnetic Properties of those metals by Prof. Ewing and Mr. Parshall, form classics of research in engineering physics; whilst the debateable questions involved in the phenomena of marine currents are discussed in the Paper on "Littoral Drift" by Mr. Wheeler.

In reference to the first-mentioned of the latter group of Communications, it may be recorded that the Council has deemed it well that the question of an authoritative definition of a standard or standards of thermal efficiency for steam-engines should be carefully



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examined, and has appointed a Committee to consider and report upon the subject.

For those whose work lies mainly in or near the Metropolis, it is possible that special interest may attach to the first Section of the Publications, which contains an account of the Proceedings in the theatre of the Institution. It is with no little satisfaction that the Council notes that four of the Papers contained in that Section have been presented by Authors practising in America. But a more striking illustration of the wide interest possessed by the publications of the Institution, is afforded by the fact that one-half of the selected Papers so far prepared for the volumes of this Session have been contributed by members whose residence abroad prevents them from attending its meetings.

### The "James Forrest" Lecture.

The fourth annual lecture of the series—"Physical Experiment in Relation to Engineering"—was delivered by Dr. Alex. B. W. Kennedy, F.R.S., M. Inst. C.E., on the 7th May; and the Council desires to record here its thanks to the lecturer, whose treatment of the subject evoked a warm expression of appreciation from those who heard him. This discourse will be printed in the concluding volume of the Proceedings of the Session.

### Students' Meetings.

The attendance at these supplemental meetings has shown some improvement, the average having been 48. Several Papers of merit have been read and discussed, and Miller prizes have been awarded to Messrs. W. O. Leitch, jun., A. S. Butterworth, E. S. MacDonald and S. Thow. The reports received from the five Local Associations indicate steady progress in every case. The Council is glad to be able, as a result of visitation by its members, to endorse these favourable statements, and takes this opportunity of thanking all those who have assisted in the development and maintenance of these important branches. Awards of Miller prizes have been made to Messrs. J. Scott and J. Andrew for Papers read before the Glasgow Association of Students, and to Mr. M. De Ville for a Paper read before the Manchester Association. The visits to engineering works, both in London and at the provincial centres, have been conducted as heretofore, although the educational value of such inspections is not yet realised by many Students, who, it is believed, might without great difficulty avail

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themselves of such opportunities. The May gathering of the Students in London has been repeated a fifth time, visits being paid to the Blackwall Tunnel and Messrs. Yarrow's works on the 14th, and to the new works and extensions of the East London Water Company on the 15th.

### The Collection of Paintings.

A portrait of the late Mr. J. F. Latrobe Bateman, Past-President, painted by Mr. Clegg Wilkinson from a photograph, has been presented by the Hon. R. C. Parsons; whilst Sir Robert Rawlinson, Past-President, has further added to the collection by the gift of his portrait, painted by Mr. Phil Morris. A list of the portraits now in the possession of the Institution, with some particulars relative to them, is appended to this report.

### The Premises.

The rebuilding having proceeded far enough to permit of the occupation of the offices in March, the temporary premises referred to in the last annual report were vacated at Lady Day, the principal portion of the library and other effects being removed into the new rooms. The main library will be finished during the forthcoming recess, when the books most in demand will be transferred into it, and the entire collection will be brought into the house. The structural alterations to the interior of the theatre will also be resumed, and it is expected completed, during the recess. Until the decoration of the interior has been undertaken —a matter of some time—an opinion upon the result generally must be premature. The work has been carried to its present stage, not without discomfort and difficulty, but without any serious dislocation of the ordinary business; and it may be predicted with confidence that in the more spacious rooms now provided will be found increased convenience and comfort for all who visit and use the Institution.

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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

### RECEIPTS.

| *Dr.* | £. s. d. | £. s. d. |
|---|---|---|
| To Balance, 1 April, 1895, viz. :— | | |
| On Deposit . . . . . | 14,000 0 0 | |
| Cash in the hands of the Treasurer . . . | 988 10 6 | |
| „ „ „ Secretary . . . | 29 10 5 | |
| | | 15,018 0 11 |
| **INCOME.** | | |
| — Subscriptions :— £. s. d. | | |
| Arrears . . . . . 718 19 0 | | |
| Current . . . . . 16,451 9 0 | | |
| Advance . . . . . 677 6 6 | | |
| | 17,847 14 6 | |
| — Minutes of Proceedings :—Re-payment for Binding, &c. . . . . | 393 8 6 | |
| — Library Fund . . . . . | 86 3 6 | |
| — Dividends : 1 year on | | |
| £ *Institution Dividends.* | | |
| 6,000 2½% Consols . . . 159 10 0 | | |
| 6,000 Metropolitan 3½% Stock 203 0 0 | | |
| 6,000 Great Eastern Railway 4% Debenture Stock. 232 0 0 | | |
| 8,000 Great Northern Ry. 3% Debenture Stock . . 232 0 0 | | |
| 6,000 Great Western Ry. 4% Debenture Stock . . 232 0 0 | | |
| 8,000 Lancs. & Yorks. 3 % Do. 232 0 0 | | |
| 6,000 London & N.W. Ry. 3% Debenture Stock . . 174 0 0 | | |
| 8,000 Midland Ry. 3% Ditto . 232 0 0 | | |
| £54,000 Nominal or par value. | | |
| 10,000 London & S. W. Ry. 3% Debenture Stock (6 months' Dividend—since sold) . . . 145 0 0 | | |
| 6,000 North Eastern Ry. 4% Debenture Stock (6 months' Dividend—since sold) . . . 116 0 0 | | |
| | 1,957 10 0 | |
| *Whitworth Legacy.* | | |
| £1,400 5% Debenture Stock in Sir Joseph Whitworth & Co., Ltd. . . . 67 13 4 | | |
| 4,000 Four hundred £10 shares in Ditto . . . . 200 0 0 | | |
| £5,400 Nominal or par value. | 267 13 4 | |
| — Rents—No. 27 Great George St. . . . . | 918 18 0 | |
| — Interest on Deposit . . . . . | 29 0 5 | |
| — Repayment of excess paid on account of Library Catalogue. . . . . | 278 9 0 | |
| | | 21,778 17 3 |
| Carried forward . . . . . | | £36,796 18 2 |

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*from the* 1ST APRIL, 1895, *to the* 31ST MARCH, 1896.

## EXPENDITURE.

*Cr.* GENERAL EXPENDITURE.

| | £. s. d. | £. s. d. | £. s. d. |
|---|---|---|---|
| By House and Establishment Charges:— | | | |
| Repairs:— General | 3 16 0 | | |
| No. 27 Gt. George St. | 5 18 2 | | |
| | | 9 14 3 | |
| Rent of No. 27 Great George Street (inclusive of agents' charges for letting offices) | | 571 19 10 | |
| Rates and Taxes:— | | | |
| Reduced { Nos. 24 & 25 Great George Street | 59 6 11 | | |
| Reduced { No. 26 Gt. George St. | 7 9 7 | | |
| No. 27 Gt. George St. | 218 0 5 | | |
| | | 284 16 11 | |
| Insurance:—Portraits, Furniture, &c. | 38 5 3 | | |
| No. 27 Gt. George St. | 1 12 0 | | |
| | | 39 17 3 | |
| Rent of Telephone | | 22 2 0 | |
| Fixtures and Furniture | | 36 19 6 | |
| Lighting and Warming:— | | | |
| General | 96 11 7 | | |
| No. 27 Gt. George St. | 16 18 6 | | |
| | | 113 10 1 | |
| Refreshments at Meetings | | 47 16 6 | |
| Assistance at Meetings | | 13 10 0 | |
| Students' Meetings and Visits | | 183 2 6 | |
| Household Expenses | | 211 16 4 | |
| | | | 1,535 5 2 |
| — Postages, Telegrams, and Parcels | | 293 9 8 | |
| — Stationery and Printing | | 642 4 4 | |
| — Watt Medals | | 4 15 0 | |
| — Stephenson Medals | | 7 2 6 | |
| — Diplomas | | 32 11 7 | |
| — Annual Dinner (balance of 1895 and part 1896) | | 273 0 11 | |
| | | | 1,253 4 0 |
| — Salaries | | 3,200 0 0 | |
| — Clerks, Messengers, and Housekeeper | | 1,128 0 0 | |
| — Retiring Allowance to late Librarian | | 200 0 0 | |
| — Donations to late Housekeeper and Messenger | | 82 0 0 | |
| | | | 4,610 0 0 |
| — Library:—Books and Periodicals | | 306 3 4 | |
| Binding | | 155 16 4 | |
| | | | 461 19 8 |
| — Publications:— | £. s. d. | | |
| "Minutes of Proceedings," Vols. cxx., cxxi., cxxii. and cxxiii. | 7,528 1 8 | | |
| Subject Index, vols. lix.–cxviii. | 1,209 9 1 | | |
| Charters, By-Laws, and Lists of Members | 324 2 4 | | |
| | | | 9,061 13 1 |
| Carried forward | | | £16,922 1 11 |

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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

### RECEIPTS—*continued.*

*Dr.*

| | £. | s. | d. |
|---|---|---|---|
| Brought forward . . . . . | 36,796 | 18 | 2 |

### Capital.

| | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|
| To Admission-Fees . . . . . | 3,071 | 5 | 0 | | | |
| — Life-Compositions . . . . . | 596 | 18 | 6 | | | |
| — Sale of £10,000 London and South-Western Railway 3 % Debenture Stock . . . | 11,616 | 11 | 6 | | | |
| — Sale of £6,000 North-Eastern Railway 4 % Debenture Stock . . . . . | 9,074 | 7 | 0 | | | |
| | | | | 24,359 | 2 | 0 |

Carried forward . . £61,156 0 2

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*from the* 1ST APRIL, 1895, *to the* 31ST MARCH, 1896.

EXPENDITURE—*continued.*

| *Cr.* | £. | s. | d. |
|---|---|---|---|
| Brought forward . . . . . | 16,922 | 1 | 11 |
| By Legal Expenses :— | | | |
| Westminster (Parliament Street) Improvements 126 0 4 | | | |
| General . . . . . 15 15 6 | | | |
| 141 | 15 | 10 | |
| — Subscription to Westminster Hospital . . . . . 10 | 10 | 0 | |
| 17,074 | 7 | 9 | |

CAPITAL.

| | | | |
|---|---|---|---|
| — New Building— | | | |
| Contract . . . . . 32,400 | 0 | 0 | |
| Architect :—Commission . . . . . 1,620 | 0 | 0 | |
| Clerk of Works . . . . . 185 | 12 | 0 | |
| Working and attending heating apparatus . . 130 | 10 | 4 | |
| Furniture . . . . . 137 | 16 | 8 | |
| Removing and Warehousing, &c. . . . . 226 | 19 | 3 | |
| Legal Expenses . . . . . 11 | 11 | 4 | |
| Miscellaneous Work and incidental expenses . 213 | 19 | 6 | |
| Repairs to temporary premises . . . . . 12 | 14 | 0 | |
| Rent of ditto . . . . . 711 | 2 | 1 | |
| Rates and Taxes on ditto . . . . . 228 | 16 | 10 | |
| Insurance of ditto . . . . . 2 | 5 | 0 | |
| Lighting and Warming of ditto . . . . . 54 | 5 | 2 | |
| 35,935 | 12 | 2 | |

Carried forward . . £53,009 19 11

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## ABSTRACT *of* RECEIPTS *and* EXPENDITURE

*Dr.*

### RECEIPTS—*continued.*

| | £. | s. | d. |
|---|---|---|---|
| Brought forward . . . . . | 61,156 | 0 | 2 |

**Trust-Funds.**

*Telford Fund.*

| | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|
| To Balance of Telford Premiums . . | | 9 | 17 | 8 | | |
| — Dividends:—1 year on | | | | | | |
| £. s. d. | | | | | | |
| 5,439 11 0 2½% Consols . . . . | | 144 | 12 | 4 | | |
| 3,299 2 0 Ditto (Unexpended Dividends) . . . | | 87 | 14 | 0 | | |
| £8,738 13 0 | | | | | 242 | 4 | 0 |

*Manby Donation.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £250 0 0 Great Eastern Ry. 4% Debenture Stock . . . . | | | | 9 | 13 | 4 |

*Miller Fund.*

| | | | | | | |
|---|---|---|---|---|---|---|
| 3,125 0 0 2½% Consols. . . . | | 83 | 1 | 4 | | |
| 2,004 17 5 Ditto (Unexpended Dividends). . . . | | 53 | 6 | 0 | | |
| £5,129 17 5 | | | | | 136 | 7 | 4 |

*Howard Bequest.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £551 14 6 2¾% Consols . . . . . | | | | 14 | 13 | 4 |

*Trevithick Memorial.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £103 0 0 2¾% Consols . . . . . | | | | 2 | 14 | 8 |

*Crampton Bequest.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £512 15 11 2¾% Consols. . . . . | | | | 13 | 12 | 8 |

*James Forrest Lectureship.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £320 0 0 South-Eastern Ry. 5% Debenture Stock . . . . . | | | | 15 | 9 | 4 |

*Palmer Scholarship.*

| | | | | | | |
|---|---|---|---|---|---|---|
| £1,381 1 6 Metropolitan 3% Stock . . . . | | | | 40 | 1 | 0 |
| | | | | | | 474 15 8 |
| | | | | | | £61,630 15 10 |

### Summary of Investments.

| | £. | s. | d. | £. | s. | d. |
|---|---|---|---|---|---|---|
| Institution Investments . . . . . | | | | 54,000 | 0 | 0 |
| Freeholds of Nos. 24, 25 & 26 Gt. George St. . | | | | 40,000 | 0 | 0 |
| Whitworth Legacy:—400 Shares of £10, and £1,400 5% Debenture Stock in the firm of Sir Joseph Whitworth and Co., Ltd. . . . . | | | | 5,400 | 0 | 0 |
| Trust-Funds Investments:— | £. | s. | d. | | | |
| Telford Fund . . . . . | 8,738 | 13 | 0 | | | |
| Manby Donation . . . . . | 250 | 0 | 0 | | | |
| Miller Fund . . . . . | 5,129 | 17 | 5 | | | |
| Howard Bequest . . . . . | 551 | 14 | 6 | | | |
| Trevithick Memorial . . . . | 103 | 0 | 0 | | | |
| Crampton Bequest . . . . | 512 | 15 | 11 | | | |
| James Forrest Lectureship . . | 320 | 0 | 0 | | | |
| Palmer Scholarship . . . . | 1,381 | 1 | 6 | | | |
| | | | | 16,987 | 2 | 4 |
| | | | | £116,387 | 2 | 4 |

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*from the* 1ST APRIL, 1895, *to the* 31ST MARCH, 1896.

EXPENDITURE—*continued.*

| *Cr.* | | | | | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Brought forward | | | | | 53,009 | 19 | 11 |
| TRUST FUNDS. | | | | | | | |
| | £. | s. | d. | | | | |
| By Telford Premiums | 156 | 12 | 7 | | | | |
| — Telford Medals | 12 | 0 | 0 | £. s. d. | | | |
| | | | | 168 12 7 | | | |
| — Manby Premium | | | | 3 9 3 | | | |
| — Miller Scholarship | 40 | 0 | 0 | | | | |
| — Miller Prizes | 51 | 13 | 3 | | | | |
| | | | | 91 13 3 | | | |
| — Crampton Prizes | | | | 44 16 3 | | | |
| — James Forrest Lectureship (Third Lecture) | | | | 15 9 8 | | | |
| | | | | | 324 | 1 | 0 |
| | | | | | 53,334 | 0 | 11 |
| — Balance, 31 March, 1896, viz.:— | | | | | | | |
| On deposit | | | | 7,000 0 0 | | | |
| Cash in the hands of the Treasurer | | | | 1,282 14 6 | | | |
| „ „ Secretary | | | | 14 0 5 | | | |
| | | | | | 8,296 | 14 | 11 |
| | | | | | £61,630 | 15 | 10 |

Examined with the Books and found correct.

(Signed) W. T. DOUGLASS, A. C. HURTZIG } *Auditors.*

JAMES FORREST, *Secretary.*
11 *May*, 1896.

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# PREMIUMS AWARDED.

## Session 1895–96.

The following is a detailed list of the Awards made for Original Communications:—

For Papers Read and Discussed at the Ordinary Meetings.

1. A George Stephenson Medal and a Telford Premium to George Frederick Deacon,[1] M. Inst. C.E., for his Paper on "The Vyrnwy Works for the Water-Supply of Liverpool."
2. A Telford Medal and a Telford Premium to Matthew Henry Phineas Riall Sankey, late Captain R.E., M. Inst. C.E., for his Paper on "The Thermal Efficiency of Steam-Engines."
3. A Telford Medal and a Telford Premium to James Alfred Ewing, F.R.S., M. Inst. C.E., for his Paper on "The Magnetic Testing of Iron and Steel."
4. A Telford Medal and a Telford Premium to John Oliver Arnold, for his Paper entitled "The Influence of Carbon on Iron."
5. A Telford Medal and a Telford Premium to George Henry Hill, M. Inst. C.E., for his account of "The Thirlmere Works for the Water-Supply of Manchester."
6. A Watt Medal and a Telford Premium to Jeremiah Head M. Inst. C.E., for his Paper on "American and English Methods of Manufacturing Steel Plates."
7. A Watt Medal and a Telford Premium to Elmer Lawrence Corthell, M.A., D.Sc., M. Inst. C.E., for his description of "The Tampico Harbour Works."
8. A Telford Medal and a Manby Premium to the Hon. Richard Clere Parsons, M.A., M. Inst. C.E., for his Paper on "The Sanitary Works of Buenos Ayres: Sewerage, Drainage and Water-Supply."

[1] Has previously received Telford and Watt Medals and Telford Premiums.

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9. A Crampton Prize to Hammersley Heenan, M. Inst. C.E., and to William Gilbert, Wh.Sc., Assoc. M. Inst. C.E., for their joint Paper on "The Design and Testing of Centrifugal Fans."
10. A Crampton Prize to Thomas Wrightson, M. Inst. C.E., for his Paper on "The Dilatation, Annealing and Welding of Iron and Steel."
11. A Crampton Prize to Horace Field Parshall, Assoc. M. Inst. C.E., for his Paper on "Magnetic Data of Iron and Steel."

FOR PAPERS PRINTED IN THE PROCEEDINGS (PART IV OF SESSION 1894–95) WITHOUT BEING DISCUSSED.

1. A Manby Premium to Bryan Donkin,[1] M. Inst. C.E., for his Paper entitled "Experiments on Centrifugal Fans."
2. A Manby Premium to Alan Brebner,[2] B.Sc., Assoc. M. Inst. C.E., for his Paper entitled "The Powers of Lighthouse-Lights by Calculation."

The Awards for Papers printed in Sect. II of the Proceedings for Session 1895–96 will be announced at the opening meeting of the next Session.

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. A Miller Prize to William Orr Leitch,[3] Jun., Stud. Inst. C.E., for his Paper on "Iron Tunnels."[4]
2. A Miller Prize to Arthur Shaw Butterworth,[3] Stud. Inst. C.E., for his description of the "Loughborough Sewage-Disposal Works."[4]
3. A Miller Prize to Edward Slater McDonald, Stud. Inst. C.E., for his account of the "Swing Bridge over the River Nene at Sutton Bridge."
4. A Miller Prize to Sydney Thow, Stud. Inst. C.E., for his Paper on "The Construction of the Molong to Forbes Railway, New South Wales."

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[1] Has previously received a Watt Medal and a Telford Premium.
[2] Has previously received a Telford Medal and Premium.
[3] Have previously received Miller Prizes.
[4] It is intended to print this Paper in the Minutes of Proceedings.

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FOR PAPERS READ BEFORE LOCAL ASSOCIATIONS OF STUDENTS.

1. A Miller Prize to James Scott, Stud. Inst. C.E. (of Glasgow), for his account of "The Lanarkshire and Dumbartonshire Railway."
2. A Miller Prize to James Andrew, Stud. Inst. C.E. (of Glasgow), for his Paper on "The Glasgow, Yoker and Clydebank Railway, Dalmuir Extension."
3. A Miller Prize to Martin De Ville, Stud. Inst. C.E. (of Manchester), for his Paper entitled "Aerial Ropeways: a Description of the Mazapel Line."

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# APPENDIX.

## LIST OF PORTRAITS IN THE POSSESSION OF THE INSTITUTION OF CIVIL ENGINEERS.

| Subject. | Born. | Died. | President. | How Acquired. | Painter. |
|---|---|---|---|---|---|
| Telford, Thomas . | 1757 | 1834 | 1820–34 | Bequest . . . | S. Lane. |
| Walker, James . | 1781 | 1862 | 1835–45 | Painted for the Institution . . | J. P. Knight, R.A. |
| Rennie, Sir John . | 1794 | 1874 | 1845–48 | ,, ,, | James Andrews. |
| Field, Joshua . . | 1786 | 1863 | 1848–50 | ,, ,, | James Andrews. |
| Cubitt, Sir William | 1785 | 1861 | 1850–52 | Presented by Jos. Cubitt, V.P. . | Sir W. Boxall, R.A. |
| Simpson, James . | 1799 | 1869 | 1854–56 | Presented by his sons . . . | Replica, Sir W. Boxall, R.A. |
| Stephenson, Robt., M.P. . . . . | 1803 | 1859 | 1856–58 | Painted for the Institution . . | Henry Phillips. |
| Locke, Joseph, M.P. | 1805 | 1860 | 1858–60 | Bequest of Mrs. Locke . . . | Sir Francis Grant, P.R.A. |
| Hawkshaw, Sir John | 1811 | 1891 | 1862–64 | Presented by Sir John Hawkshaw | T. Collins. |
| M'Clean, John Robinson, M.P. . | 1813 | 1873 | 1864–66 | Presented by his son . . . . | Charles Landseer R.A. |
| Fowler, Sir John, Bart., K.C.M.G. | 1817 | .. | 1866–68 | Presented by subscribers. . . | Sir John Millais, P.R.A. |
| Gregory, Sir Chas. Hutton, K.C.M.G. | 1817 | .. | 1868–70 | ,, ,, | John Collier. |
| Hawksley, Thomas | 1807 | 1893 | 1872–74 | ,, ,, | H. Herkomer, R.A. |
| Harrison, Thomas Elliot . . . | 1808 | 1888 | 1874–76 | Painted for the Institution . . | Replica, W. W. Ouless, R.A. |
| Bateman, J. F. Latrobe . . . | 1810 | 1889 | 1878–80 | Hon. R.C. Parsons, M. Inst. C.E. . | Clegg Wilkinson. |
| Abernethy, James | 1816 | 1896 | 1881 | Presented by his sons. . . . | W. M Palin. |
| Bazalgette, Sir J. W., C.B. . . | 1819 | 1891 | 1884 | Presented by Lady Bazalgette . . | Replica, — Ossani. |
| Bramwell, Sir Frederick, Bart. | 1818 | .. | 1885–86 | Presented by subscribers. . . | F. Holl, R.A. |
| Bruce, Sir George Barclay . . . | 1821 | .. | 1887–89 | ,, ,, | W. M. Palin. |
| Rawlinson, Sir Robert, K.C.B. | 1810 | .. | 1894–95 | Presented by Sir Robert Rawlinson . . . . | Phil Morris, A.R.A. |

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LIST OF PORTRAITS—*continued.*

| Subject. | Born. | Died. | How Acquired. | Painter. |
|---|---|---|---|---|
| Brunel, Isambard Kingdom, Vice-President . | 1806 | 1859 | Presented by his sons | J. C. Horsley, R.A. |
| Miller, Joseph, Member of Council . . . . | 1797 | 1860 | Painted for the Institution . . . . | Sir W. Boxall, R.A. |
| Siemens, Sir William, Member of Council . | 1823 | 1883 | Presented by Lady Siemens . . . . | Rudolf Lehmann. |
| Brassey, Thomas . . | 1805 | 1870 | Presented by H. P. Burt, Assoc. Inst. C.E. . . . . | J. B. Hallé. |
| Wilson, General Alexander . . . . . | 1776 | 1866 | Presented by his family | Unknown. |
| Manby, Charles, Secretary . . . . . | 1803 | 1884 | Presented by T. R. Crampton, M. Inst. C.E. . . . . | Sidney Hodges. |
| Forrest, James, Secretary | 1825 | .. | Presented by the Council . . . . | W. M. Palin. |
| Boulton, Matthew . . | 1728 | 1809 | Presented by George Rennie, M. Inst. C.E. | Unknown. |
| Brindley, James . . . | 1716 | 1772 | Presented by Sir John Hawkshaw, Past President . . . | F. Parsons. |
| Huddart, Joseph . . | 1740 | 1816 | Presented by James Walker, Past President . . . . . | Wildman, after Hoppner. |
| Jessop, William . . . | 1745 | 1813 | .. .. | Edwin Williams. |
| Rennie, John (senior) . | 1761 | 1821 | Presented by Sir John Rennie, Past President . . . . . | Raeburn. |
| Stephenson, George . . | 1781 | 1848 | Presented by George Robert Stephenson, Past President . . | J. Lucas. |
| Stephenson, George and Robert . . . . . | .. | .. | Purchased by the Institution . . . . | J. Lucas. |
| Stephenson, Robert (study for Britannia Bridge group) . . . | .. | .. | „ „ | J. Lucas. |
| Smeaton, John . . . | 1724 | 1792 | Presented by Alfred Burges, M. Inst. C.E. | Wildman, after Gainsborough. |
| Whidbey, Joseph . . | .. | 1833 | Presented by George Rennie, M. Inst. C.E. | J. Ponsford. |
| Bidder, George Parker, as a child (the "calculating boy") . . . | 1806 | 1878 | Presented by the Nelson family . . . | .. |
| Conference of Engineers at the Britannia Bridge (portraits of leading members of the profession in 1850) . . | .. | .. | Presented by George Robert Stephenson, Past President . . | J. Lucas. |

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# SUBJECTS FOR PAPERS.

## Session 1896–97.

The Council of The Institution of Civil Engineers invites Original Communications on the Subjects included in the following List, as well as on any other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council has the power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces a gross amount of £235 annually.

2. The Manby Donation, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises nearly £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years. No Paper will be received from a Student in competition for the Miller Scholarship and the Miller Prizes when he has become qualified by age, viz. twenty-five years, for election into the Corporation.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly £15. It has been arranged to award this prize every five years,



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commencing from 1877. The next award will therefore be made in 1897.

5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15*s.* 11*d.* 2¾ per cent. consols, and the income arising therefrom is now £13 14*s.* This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0*s.* 9*d.*, has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2¾ per cent. consols, upon which the interest is £2 15*s.* a year.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests, which are limited by the donors.

LIST.

1. The most economical Methods of Handling large masses of Excavation, as exemplified in modern canal construction.
2. The Measures necessary for the improvement of Canal Navigations.
3. The Methods adopted in carrying out large Dock and Harbour Works, with descriptions of the Plant employed.
4. The Appliances for Dredging and for Removing Rock in deep water, with details of the time occupied in the various operations.
5. The Application of Compressed Air, steam and hydraulic power to Rock-drills.
6. The Design and Construction of Railway Carriages, having reference to (*a*) lavatory accommodation; (*b*) provision for refreshments; and (*c*) sleeping arrangements.
7. The Modern Methods of Pumping compared as to cost and efficiency.
8. The Use of Steel in the Construction of large Tanks.

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9. The Employment of Storage-Reservoirs in Irrigation and in the Conservation of Rivers.
10. The Purification of Sewage by precipitation, filtration, electrolytic, bacteriological and chemical processes.
11. The Use of Ash-bin Refuse in towns for the production of steam.
12. The Purification of large quantities of Water after its use in Manufactories.
13. The Methods of Enriching Coal-Gas and their effect on its calorific and illuminating values.
14. The Production and Enrichment of Water Gas.
15. The methods of conveying and of using Natural Gas.
16. The Construction and Use of Water-Tube Boilers.
17. The Utilization of Heat (*a*) generated in the compression of air and other gases; (*b*) carried away by steam-engine condenser-water; and (*c*) contained in boiler-furnace flue-gases.
18. The Methods of Condensing Steam by the use of moderate quantities of water.
19. The Methods of removing Moisture from Steam, and of reducing losses by radiation from steam-pipes.
20. The Production and Use of Super-heated Steam.
21. The Theory and Development of the Compound Steam-Turbine.
22. The Application of Oil- and Gas-Engines to tractive purposes on common roads and on tramways, and to the propulsion of vessels.
23. The Design and Construction of large Turbines.
24. The Forms of Turbine most suitable for small Falls.
25. The Methods of Testing the Lubricating Values of Oils, Greases, etc.
26. The Comparative Merits of Blast- and Reverberatory Furnaces.
27. The Manufacture and Use of Steel for Electro-magnetic Purposes.
28. The Manufacture of Steel for Structural Purposes.
29. The Use of Steel of great tensile strength in Ships and other structures.
30. Recent improvements in the Manufacture of Armour-Plates.
31. The Strength of Steel Shafts, Tubes and Cylinders.
32. The Mining of Thin Seams of Coal.
33. The Underground Arrangements in Collieries.
34. The Influence of Coal-dust in contributing to Colliery Explosions.



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35. The Use of Electrical Energy in working Mines.
36. The Drainage of Mines by Pumping and by Tunnelling.
37. The Extraction of Metals from their Ores by electrolytic processes.
38. Argentiferous Lead Smelting in Water-jacketed blast-furnaces.
39. The Methods of Gold-mining in California.
40. The Occurrence, Production and Uses of (*a*) Asbestos, (*b*) Arsenic, and (*c*) Mercury.
41. The Metallurgy of Chromium, Molybdenum and other rare metals, and their use in the Manufacture of Steel.
42. The design, construction, erection and working of Modern Stamp Mills.
43. The Machines for Raising Mineral Tailings, as lifting-wheels, pumps, dredgers, etc.
44. The most suitable Steam-power Equipments for Electric-light stations.
45. The Utilization of Electric-Lighting Plant during hours of small demand.
46. The Utilization of Electrical Energy in the form of heat.
47. The Regulation of Electric pressure in large lighting circuits as carried out at the engine, the dynamo, or the exciter.
48. The Theory and Practice of the Transmission of Power by Alternating Currents.
49. The Use of Electrical Motors for driving machines in textile factories and in engineering workshops.
50. The first cost, facility and economy of operation of Electrical Traction on Railways with heavy trains and on Tramways.
51. The Municipal Control of Tramways with a view to their working electrically, in conjunction with electric lighting.
52. The Construction and Working of Electrical Lifts and Cranes.
53. The Electrolytic Action of Return Currents in Electrical Tramways on gas- and water-mains, and the best means of providing against Electrical Disturbances.
54. The most suitable Alloys for the working parts of Pumps for lifting corrosive liquids from mines, etc.
55. The Methods of Preventing or Arresting the Corrosion of Hydraulic Rams of large diameter.
56. The Use and Durability of Cast Iron Pipes and other structures in contact with various soils.
57. The Durability of Wrought Iron and Steel Structures exposed to fresh, salt and brackish water.
58. The Use of the Die-press in workshop operations.
59. The Appliances used in the Manufacture of Smokeless Powder.

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60. The different systems of Refrigeration, and of appliances for the storage and Preservation of Food Produce.
61. Brine-pumping and the Manufacture of Common Salt.
62. The present Limits of Speed at Sea.
63. The most recent types of (*a*) Passenger and Mail Steamers; (*b*) Cargo-Steamers.
64. The Relative Advantages of Single-Screws, of Twin-Screws, and of Triple-Screws in large vessels.
65. The Use of Electrical Machinery for lighting and the transmission of power in warships and in the mercantile marine.
66. The best position for Torpedo-Discharging Tubes on large vessels, with a fixed direction, or trainable.
67. The Progress of Telegraphy and Telephony at home and abroad.

### Instructions for Preparing Original Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations should be drawn on drawing- or tracing-paper, to as small a scale as is consistent with distinctness, and figured dimensions should be introduced only where necessary. When an illustrated communication is accepted for reading, a series of Diagrams will be required so drawn and coloured as to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, will not be accepted. According to the By-laws every Paper presented to the Institution is deemed to be its property, and may not be published without the consent of the Council.

The Communications must be forwarded to the Secretary, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in the succeeding one.

James Forrest, *Honorary Secretary*,
J. H. T. Tudsbery, *Secretary*.

The Institution of Civil Engineers,
*Great George Street, Westminster, S.W.*
*August*, 1896.

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EXCERPT BY-LAWS, SECTION XV, CLAUSE 3.

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Napier, J.
Navy Department, Washington, U.S.A.
Neues, J. M. F.
Newcastle-upon-Tyne Public Libraries.
New Decimal Association.
Newell, F. H.
New England Cotton Manufacturers' Association.
New York State Board of Health.
New Zealand Institute.
New Zealand University.
North, E. P.
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North of England Institute of Mining and Mechanical Engineers.
North Staffordshire Institute of Mining and Mechanical Engineers.
Nova Scotian Institute of Science.

O.

O'Connor, C. Y.
Odling, C. W., M.E.
Oesterreichischer Ingenieur-und Architekten-Verein.
Ordnance Committee.
Ordnance Office, Washington, U.S.A.
Owen, F.
Owens College, Manchester.

P.

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Peckham, S. F.
Peirce, W. G.
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Permanent-Way Institution.
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Philosophical Society of Glasgow.
Physical Society of London.
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Pierce, J., Jun., M.A.
Platt, S. S.
"Politecnico, Il."
Pollitzer, S.
Pomeroy, L. R.
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"Przegląd Techniczny."



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## Q.

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## R.

Radcliffe Library, Oxford University Museum.
Railway Commissioners of New South Wales.
"Railway Engineer, The."
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Rathbone, E. P.
Ravenshaw, H. W.
Rawlinson, Sir R., K.C.B.
Raymond, Major C. W.
Reade, T. M.
Reale Accademia dei Lincei, Rome.
Reale Istituto d'Incoraggiamento di Napoli.
Reale Istituto Lombardo di Scienze e Lettere.
Redgrave, G. R.
Regio Istituto tecnico superiore di Milano.
Reuleaux, Prof. Dr. F.
Reunert, T.
"Revista de Obras Publicas," Lisbon.
"Revue générale des Chemins de Fer."
"Revue industrielle."
"Revue technique, La."
Richard, G.
Richards, Admiral Sir G. H., K.C.B., F.R.S.
Richards, R. W.
Richardson, Mrs. C.
Riggenbach, N.
Ritter, Prof. W.
Robinson, Prof. H.
Robinson, J. P.
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Roll, O. N.
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Russell, H. C.

S.

St. George, P. W.
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Saner, J. A.
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Sautter, —.
Sauvage, E.
Savage, H.
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Society of Arts.
Society of Engineers.
South African Association of Engineers and Architects.
South Australian Railway Commissioners.
South Wales Institute of Engineers.
Sowerby, W.
Spolku Architektů a Inženýrů v království Českém.
Spon, E. and F. N.
Spooner, H. J.
Spring, F. J. E., C.I.E.
Stanley, H. C.
Stanley, W. F.
State Engineer and Surveyor, New York.
Steiger, A.
Stoke Newington Public Library.
Stone, E. H.
Stoney, F. G. M.
"Street Railway Journal."
Strobel, C. L.
Strub, E.
Superintendent of Government Printing, Calcutta.

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Surgeon-General, U.S. Army.
Survey of India Department.
"Surveyor, The."
Surveyors' Institution.
Svenska Teknologföreningen.
Sweny, M. A., R.N.
Sydney University.
Symons, G. J., F.R.S.
Syndics of the Cambridge University Press.

T.

Tatton, R. A.
Tayler, A. J. W.
Technical Society of the Pacific Coast.
Technische Staatslehranstalt in Chemnitz.
Technological Museum, Sydney.
Terry, S. H.
Thomas, W. H.
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Timmins, S.
Tomlinson, S.
Toronto University.
Tourtsevitch, I.
"Transport."
Tratman, E. E. R.
"Travelers' Official Guide of the Railway and Steam Navigation Lines in the United States and Canada."
Trevithick, R. F.
Trinity University, Toronto.
Trouvé, G.
Tylor, J. J.

U.

Unione Tipografico - Editrice Torinese.
United States Artillery School.
United States Coast and Geodetic Survey.
United States Department of Agriculture.
United States Geological Survey.
United States Naval Institute.
United States Patent Office.
University College, Bristol.
University College, Liverpool.
University College, London.
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V.

Valentini, C.
Vauthier, L. L.
Ventris, A.
Verdinois, C.
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Verein für Eisenbahnkunde zu Berlin.
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Victoria University, Manchester.
Victorian Railways Commissioners.
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Vosmaer, A.

W.

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Webb, F. W.
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Weedon, J. F.
Western Society of Engineers, Chicago.
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| Ashenden, P. | 1 | 1 | 0 |
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| Berry, R. A. J. | 1 | 1 | 0 |
| Broad, A. E. | 2 | 2 | 0 |
| Bruce, R. A. | 1 | 1 | 0 |
| Burn, G. F. | 1 | 0 | 0 |
| Bush, Robert | 2 | 2 | 0 |
| Chapman, S. C. | 3 | 3 | 0 |
| Dearden, H. | 3 | 3 | 0 |
| Donald, P. D. | 1 | 1 | 0 |
| Douglass, J. R. | 1 | 1 | 0 |
| Douglass, W. L. | 1 | 1 | 0 |
| Gilbert, T. S. | 1 | 1 | 0 |
| Good, R. H. | 1 | 1 | 0 |
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| Head, d'E. P. | 5 | 5 | 0 |
| Hobrough, A. | 1 | 1 | 0 |
| Jenkin, C. J. | 1 | 1 | 0 |
| Judd, J. H. | 2 | 2 | 0 |
| Lloyd, R. S. | 10 | 10 | 0 |
| Miller, J. E. | 1 | 1 | 0 |
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| Carried forward | £50 | 7 | 0 |

| | £. | s. | d. |
|---|---|---|---|
| Brought forward | 50 | 7 | 0 |
| Pierce, H. | 1 | 1 | 0 |
| Poole, Wm., Jun. | 2 | 2 | 0 |
| Reid, K. | 2 | 2 | 0 |
| Rowney, G. A. H. | 1 | 15 | 0 |
| Schwartz, A. | 1 | 1 | 0 |
| Scriven, C. W. | 1 | 1 | 0 |
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| Squire, S. N. | 2 | 2 | 0 |
| Stainton, F. C. | 2 | 2 | 0 |
| Sykes, C. F. | 2 | 12 | 6 |
| Taylor, N. M. | 2 | 2 | 0 |
| Thompson, John (Smyrna) | 1 | 1 | 0 |
| Watkins, S. | 1 | 1 | 0 |
| Watson, Thos. | 1 | 1 | 0 |
| Webster, Henry | 1 | 0 | 0 |
| Willet, A. W. | 1 | 1 | 0 |
| Wolfenden, B. J. | 2 | 2 | 0 |
| Wrench, F. H. | 1 | 1 | 0 |
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## EXTRA MEETING.

7 May, 1896.

JOHN WOLFE BARRY, C.B., F.R.S., Vice-President, in the Chair.

# THE "JAMES FORREST" LECTURE.

Mr. JOHN WOLFE BARRY, Vice-President, said that in the unavoidable absence of the President, Sir Benjamin Baker, it was his duty to undertake what was almost a work of supererogation and introduce the lecturer, Dr. Kennedy, who would deliver the lecture which was associated in their minds with their old and valued secretary, Mr. James Forrest; and he was quite certain that Dr. Kennedy would lay before the meeting that which would be of the greatest possible interest to all members of their profession, because he was about to deal with a subject that he had made peculiarly his own.

## "Physical Experiment in Relation to Engineering."

By Dr. ALEXANDER BLACKIE WILLIAM KENNEDY, F.R.S., M. Inst. C.E.

IT has been the expressed wish of the gentleman in whose honour the "James Forrest" lectures have been instituted, that they should deal with the relation of various sciences to our own profession. To those of us (and they are many) who have long enjoyed his friendship, and who are to some extent familiar with the extent to which our profession is in his debt in matters innumerable, it is practically a duty to meet his wishes in such a matter. But it must be acknowledged that the duty—as regards the lecturer—must grow every year more difficult, as the field becomes limited by his predecessors; and even at present it was with no little nervousness as to the selection of a subject that I accepted last year the invitation to give this lecture in 1896.

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There is perhaps no science, except those in the biological group, of which it might not be argued, with some degree of plausibility and reasonability, that the profession to which we all belong was a direct application. The sciences of mathematics and of physics, of chemistry and of geology, concern themselves with the exact statement of the nature and relations of facts and phenomena with which we as engineers have continually to concern ourselves. But the point of view of the purely scientific investigator and of the engineer, in regard to these facts and phenomena, are no doubt very different. In rare and exceptional cases, one man can play both *rôles*, but this happens so very seldom that for all practical purposes they may be regarded as distinct from each other. And no one who is not terribly narrow—on one side or the other—would deny that either might form a worthy life-work for any man, however high his aims or ambition.

I excepted just now the biological sciences from those with which engineers were directly in touch. But, in spite of this, I confess that I have had a great wish for years past to devote some time to the working out of a theory of evolution in relation to engineering design and progress. I cannot help thinking that there is something in relation to things inorganic which closely resembles the position of natural selection in the organic world. The struggle for existence, which too obviously exists among engineers themselves regarded as organic beings, seems also to exist in effect among engineering productions. There is also among them a survival of the fittest, and the laws which determine what is the fittest at any time, and how the standard of fitness alters as time goes on, are probably capable of fairly exact statement—in correlation with the laws of general human progress; at any rate they are very well worthy of examination. This biologico-engineering investigation would be no doubt rendered more difficult by the fact that artificial selection continually comes in to help and accelerate, or it may be to hamper and impede, but in any case to modify, the inorganic equivalent of natural selection. I have found this whole subject a most tempting one, full of fascination, and to some extent also of surprises. But finally I felt constrained to leave it, at least as far as this lecture is concerned, to someone—some fortunate person—whose mind was not so overcrowded with the innumerable details of everyday work as my own, or who was able, in spite of these details, to obtain at the same time a broad and comprehensive view of the whole subject from a point higher and more commanding than any that I seemed able to attain to. I hope that in some future year I may have the

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pleasure of listening to a "James Forrest" lecture in which "Evolution in Engineering" may be adequately dealt with. For myself, I have found it necessary to be content with a much more limited subject, although one perhaps on which my own work gives me more right to speak, "Physical Experiment in Relation to Engineering."

We are all at this present time so familiar with the idea of physical laboratories—places in which physical experiment is carried out systematically and continuously, both for purposes of scientific investigation and of education—that it is hard to realise how very modern an institution the physical laboratory is. Until quite lately the most distinguished investigators worked in laboratories which they had made for themselves and which were essentially their own private studies. The Royal Institution laboratories—originally, I think, rather chemical than physical in conception, but nevertheless always to a great extent also physical—were early and notable extensions of the purely private laboratory, and happily exist still to furnish admirable physical work. But it is practically only within the last thirty years that physical laboratories, as we know them to-day, have come into existence. Thanks very much to this growth of experimental and physical teaching, we have now an army of trained physical investigators distributed all over the country, whose principal occupation (besides teaching) is the making of researches in experimental physics, and in this way contributing to our knowledge of the phenomena of the world around us, the phenomena which it is our business to turn to "the use and convenience of man." Not only this, but within the last twenty years there have come into existence numerous well-equipped engineering laboratories, in connection with our technical colleges and schools. These engineering laboratories are, of course, simply physical laboratories modified in a certain special direction for our special purposes, and the investigations carried on in them are of the nature of physical experiment as fully and completely as those which are carried out in physical laboratories proper. The aim and scope of the two classes of experiment, however, differ considerably, as do their relations to our own work, and it will be my object this evening to put before you what, according to my own view, are the relations between these classes of experiment, and especially between each class and our own work. I need hardly say that I am bound to look at the whole matter throughout from the point of view of the engineer. I do not for a moment pretend that I am capable of taking up the position of the physicist, and

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of course I keep in mind also that I have to speak to an audience consisting essentially of engineers, and not of physicists.

Physical experiment, so far as it has relation to our own profession, may fairly be considered to serve three distinct purposes. In the first place, from the purely academic or educational point of view, it is most important and helpful in the training of engineering students. (And it is well to remember that although a great many of us never were engineering students, nor had any opportunity of obtaining such training, yet the most conservative must now recognize that in the future our sons and successors must look on the student stage as being as essential as the pupilage or the apprenticeship.) Then, secondly, what may be called purely physical experiment is necessary to supply us with all our most important constants, whether connected with the thermal properties of steam, the density of water, the electromotive force of a Clark cell, the elasticity of steel, the coefficient for a *vena contracta*, or a thousand other matters of similar nature. Lastly, technical experiments, which are essentially physical experiments, but of a much more complex nature than those of the physical laboratory (although not on that account more difficult to carry out), are necessary for determining many technical matters; such, for example, as the efficiency of a dynamo, the steam consumption of an engine, the flow of a river, the resistance of a ship, or the deflection of a girder under a moving load.

Let us consider, in the first place, the purely educative or academic type of experiment. Here the first requirement is the very simple one—which indeed may be served by an endless variety of experiments, extending far beyond the limit of Physics—that the student should learn first to see and to measure, and then to write down what he has seen and measured. (Anyone who has had to do with laboratory work knows very well how necessary it is to differentiate in this fashion.) The experiments require to be, as far as possible, quantitative rather than merely qualitative; but, otherwise, the simpler they are the better. It is unnecessary here to go into any details about them, but with a view to emphasising their importance, it is worth while just to look for a moment at the sort of thing by which, in actual engineering work, these simple experiments may be said to be represented. Perhaps those whose work lies greatly in experimentation, like my own, know best how very hard it is to find assistants, unless they have been trained in a laboratory, who can be trusted at first even to take quarter-hourly readings of a steam

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gauge or a counter, or any such duty, ridiculously simple and easy as it appears. To ask an untrained man to count the revolution of an engine which has no continuous counter attached, or to read the dials of an ampere-hour meter at exactly regular intervals of time, is merely to court disaster! The story is familiar of how Robert Houdin had so trained his faculty of general observation, that one look at a shop window would impress its contents on his mind more vividly and accurately that ten minutes of hard looking would do in the case of an ordinary man. It is really just the same with the simplest of our observations. The ordinary mind does not naturally and at once see, and see accurately, the simplest thing that is before the eyes. One has to look, to exercise conscious mental effort, as well as merely to see, and we all of us require to be taught how to look, even in these most simple matters. And when the enforced looking has to be done at exactly a particular time and no other, the average mind is apt to find the whole process an intolerable burden, all the more because it is inclined to despise the work as being too childishly easy for consideration at the very time when it is failing to carry it out!

So far as concerns the training of the faculties of observation at the stage of which I am speaking, probably chemical experiments would serve as well as physical. In certain respects possibly they might even be better, but with this we need not now concern ourselves. An important point is, perhaps, that in their earlier stages the student should not be allowed in any way to get the notion that his experiments are more than mere rough exercises. Any standard of accuracy which he can possibly attain is comparatively a very low one, and by the nature of the case the experiments he can do must be simplified down enormously before they can be put into his hands, so that at best he is only making a rough determination of one element in an artificially simplified operation, the full conditions of which he is not even in any position to understand. The actual figures which are obtained by him can under no circumstances be regarded as having any intrinsic value; and one of the difficulties of the case is, no doubt, to persuade the student to exercise his highest degree of care in obtaining results which at the same time he is told, or knows, are of no use whatever. The engineering student, I am sorry to say, is generally a terrible utilitarian. The unhappy professor has to enter into all kinds of subterfuges to get him to take an interest in, or do any careful work at, matters which the omniscience of youth has once pronounced to be "useless." Later on, of course, he is wiser and a

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trifle less narrow-minded; but I suppose the stage of first-yearness is one through which all of us have to pass in one fashion or another, to the grief of our pastors and masters, and to our own later regret.

More interesting to most of us, perhaps, than this purely academic matter is the consideration of physical experiment under the last two headings which I have mentioned.

First among these comes experiment which really belongs to pure physics, but in which we engineers may claim to be as much, or even more, concerned than the physicists, although both the difficulty and the honour of the experiment must fall to them. I suggest that we are even more concerned than the workers in pure science for two reasons, of which the first is that the whole of our interest is practically concentrated on what constitutes only a small part of the boundless region open to the physicist. He can spread his affections over glass and sealing-wax, and let them roam from ice to iron. We have only one love, or at any rate never stray very far from a limited number of matters which concern what I have heard contemptuously called "technical materials." He interests himself legitimately and equally in Argon and Carbon, in Steam and in Ethyl-Alcohol; he loves to extend his thermal conditions so as to get liquid air or gaseous carbon. We, on the other hand, are compelled to deal not only with a very small number of materials, but with these materials only in states in which we can readily obtain them. In fact, as every one knows, nineteen-twentieths of our liquid and gas problems affect only liquid and gaseous (or vaporous) water, and only the remaining small percentage is left to be distributed between coal-gas and producer-gas, liquid carbonic acid and anhydrous ammonia, and so forth. So far as the more or less "permanent" gases are considered, our interest is throughout perhaps rather chemical than physical.

Then, again, we may claim to have a first interest in certain physical results because of the extraordinary frequency with which we have somehow or other actually to make use of them—I mean a real live use, and not merely a use in an examination question, or in a text-book or a lecture. Not only would our whole work become mere guess-work without the knowledge of these results, but, having this knowledge, we are compelled by the very nature of our work to make such continual use of it that probably we are often more familiar both with the figures concerned and with the phenomena which they represent, than even the men to whose magnificent accuracy and unlimited diligence we owe their original investigation and determination. I mean,

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of course, such results as refer to the thermal relations of water and steam, to the calorimetry of fuels generally, to many hydrodynamic problems, to most problems in elasticity and what is clumsily called the strength of materials, to frictional questions, to innumerable problems relating to electrical matters, and certainly to an enormous number of matters bearing on mechanics, which, of course, is to be considered as a branch of physics.

I feel so strongly this sense of our paramount interest in certain physical problems that I have not hesitated sometimes to resent the way in which physical writers and speakers are occasionally inclined to instruct us how to express our ideas, for example, as to mass and weight, and sundry vital matters of that kind. I really think that people who have to deal with these matters as much, as often, and as thoroughly as we have, and who are on the whole reasonably competent beings, may be assumed to know how best to manage our own affairs in these respects. Mechanics are to us the breath of our nostrils, and not a mere vehicle for examination papers; and it should be remembered that the requirements of the latter case may be very different from those of what I may venture to call "real life."[1] It would perhaps be hardly proper or even safe, that I should here say anything, as I am much tempted to do, as to the vexed question of units, which from time to time seems to agitate many minds. Let me only suggest that, on the whole, it does not seem to me that the people who would be most affected by the change are at present those who are most anxious for it. In fact, admitting certainly a few notable and very distinguished exceptions, it really seems as if engineers in general were content to go on in their own way, unconscious of the terrible pitfalls and difficulties by which it is understood that they are surrounded on all hands. I quite admit, of course, that it by no means follows that the pitfalls do not exist, although I confess to being somewhat sceptical about their reality.

But having spoken so strongly of engineers as being the users of certain physical results, I must look at the other side of the matter. We engineers may have, as I urge, more interest in these matters than anyone else, but it is certainly true that we have not ourselves to thank for the determination of the results which we require and which we make so much use of. For practically the whole of these results—results without which, as I have said,

[1] I have cancelled a remark which I made here as to the misuse of "g," as I find it was based on an error of memory.—A. B. W. K.

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our profession would hardly exist, would at best be a mere trade instead of (as we are proud to consider it) a scientific profession—we are indebted to workers in physical science pure and simple, men without the least taint or suspicion of technical or utilitarian intent.[1] It would therefore ill become us engineers if we were to say or do anything which should, even in the most indirect fashion, tend to belittle the work of pure physicists, on which every day shows us more how much we are dependent. Our gratitude is so real and so deeply seated that we need not, and do not, even resent the expression of regret which has sometimes been heard from a physical worker, that what he has done should be of any "use" whatever!

A physical experiment such as is necessary for the determination of any one of the physical constants which we have in continual use differs very essentially from such experiments as we engineers have to carry out in the course of our own work. It is at once much simpler and much more difficult. It is simpler because its object is the solution of one certain problem, which has been by much care and pains isolated from all its surroundings, from all related and, so to speak, adjacent problems. The first work of the physicist, dealing with his problem, is in fact to find out a way of so isolating his question that its solution may give him exactly the one quantity he wishes to know and no other. Of problems of this kind I confess I speak as an outsider, but as an outsider it has been to me often a matter of the greatest interest and even wonderment to see what enormous pains a physicist takes, and must necessarily take, to make sure that he is measuring exactly the thing he wishes to measure—that thing, that whole thing, and nothing but that thing; to see also what innumerable precautions he has to take to ensure the absence of minute errors, or to find out where any such errors might occur, and whether they have occurred, and to evaluate them if they are unavoidable. I have found, too, that in such cases suggestions derived from my own experience in engineering experiment have been often received with a coldness which I am afraid was no more than they may have deserved! For, as I shall endeavour to show, the conditions under which experiments of this kind have to be made are absolutely different, both as to aim and method, from

[1] I think probably the only notable exception to be made in this matter is in regard to scientific experiments relating to strength and elasticity, some of which have been made by engineers and with a more or less definitely technical intention. But probably such men as Bauschinger, Martens and Tetmajer are to be considered essentially as in the position of physical workers.



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those of the experiments—more technical if not less physical—which we have to carry out for ourselves in our own work.

In a physical experiment of the second category, such as those of which I have been speaking, the primary points may be said to be, first, that the object of the experiment should be single, definite, isolated, separable and separated from all surroundings; secondly, that it should be general in its nature, and should not relate merely to one special case; next, that as a problem it should be capable of exact determination; and lastly, that the final result should be as nearly absolutely accurate as it is possible for any physical determination to be. Take as examples such matters as the determination of the density of steam, of the variation of the specific heat of water with change of temperature, of the calorific value of pure carbon, or of the mechanical equivalent of heat. These problems properly stated admit each of one exact solution, one answer which is absolutely right, even in the mathematical sense of that phrase. It is the highest object of the physicist, in dealing with such a problem, to obtain the right solution. He spares no pains to obtain it, he determines each minute correction with the patience and care of a man who knows that the value of his whole work may be vitiated by a single overlooked source of error, even of the smallest magnitude. We engineers are possibly in some danger of forgetting occasionally, in view of the familiarity and matter-of-courseness of certain figures with which we have frequently to deal, that just these everyday and familiar numbers, on account of their very importance, are those which have required and obtained for their determination the most careful, exhaustive, and accurate experimentation in the hands of the most experienced physicists.

After speaking in this fashion of the nature of experiments in pure physics, it may sound at first absurd, but it is nevertheless true, to say that physical experiments in the third category—the technical experiments which we engineers have so often actually to carry out—do not fall under a single one of the conditions which I have just given as characteristic of experiments in pure physics. We cannot, even under the most favourable circumstances, put before ourselves exact and isolated problems; we have much more often to deal with special than with general cases; we cannot choose problems which are capable of finally exact solution; and, therefore, lastly, we should treat the matter entirely wrongly if we attempted to obtain more than a certain limited degree of accuracy in our solution—an accuracy very limited indeed when compared with the all but mathematical accuracy with which problems in pure physics can be solved.

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The conditions under which engineers have to carry out physical experiments, of course, vary very greatly. In certain simple cases they are essentially physical investigations, be it in connection with friction, with elasticity, or what not, which at first sight do not greatly differ from the experiments which I have just discussed. There is probably, however, more difference than appears at first sight, although the spirit in which both sets of experiments have to be made is the same. Take as an example the determination of the elastic modulus (or the specific extension) of a piece of steel. Probably, with very perfect instruments and with extreme care in manipulation, a value of the modulus could be obtained which should be accurate, say within 1 in 2,000, for that particular piece of steel. But a figure so obtained would not be accurate even for other pieces of steel made at the same time, and out of the same ingot as the one experimented on; while, of course, there is no one absolute value for the modulus of elasticity of the widely-differing material of which all sorts go by the name of steel. Under such conditions—and I have chosen a particularly favourable example—it would be mere affectation, and, in addition, would be actually misleading, to claim anything like physical accuracy for our results. Indeed, I must go further and say that the truly scientific way of treating an experiment in engineering physics is to recognise from the outset its limitations as to accuracy, and to be careful not to state a final result in a form which should lead to the supposition of any greater degree of accuracy than that which the conditions of the work can actually allow.

The difference between physical and technical experiments may easily be illustrated by another example from the region of elasticity. The determination of the deflection of a beam, transversely loaded, as a physical experiment would resolve itself into the test of the behaviour of a piece of homogeneous material, preferably of the simplest possible cross-section, probably rectangular. It would be a matter of importance to ensure that the material was exactly of a certain chemical nature, and that it was mechanically free even from the slightest defects; it would also have to be machined to certain exact dimensions. Even with every care, the almost unavoidable imperfections in the material, minute variations in uniformity of structure, and so on, would be very difficult to deal with and to allow for. As a technical experiment, on the other hand, the beam might consist of plate and angle-bars secured together by rivets, the whole forming a structure with absolutely no pretence to homogeneity, nor to absolute exactness of dimension. Its rough surface would be



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carefully left intact, and not in any way machined, its riveted parts would be brought together as well as was reasonably possible with the appliances at the command of the engineer, but without any attempt to make a special fit between surfaces. In fact, the whole thing would be intentionally constructed as nearly as possible in the way in which a riveted beam, such as is used as a girder, is usually made. The result obtained would obviously not be a general one applicable to steel as a material, or to beams as geometrical forms, because the data of the problem, even the dimensions of the beam itself, could not be determined with minute accuracy, nor would the actual final result be comparable in accuracy with the determination of the similar problem treated from the purely physical point of view. Hence, as the experimenter cannot for a moment pretend, and should not for a moment delude himself into supposing, that his results can be more accurate than his data, it is his first duty in this line of work to find out within what limits of accuracy his experiment can be carried out, and, when he has obtained his results, to state it only within these limits. Under these conditions the statement of a result in round figures is often much more accurate than its statement down to the last decimal place which appears in the arithmetic. I have heard it said by some of the students of the greatest of our physicists, Lord Kelvin, that this was a point upon which, even in a great deal of purely physical work, their master always insisted most strongly. But I am afraid that it must be admitted, as a weakness of much of our engineering experimentation, that its results are given in figures which are absolutely ludicrous as indicating the value of the quantities actually measured. In these matters, perhaps, our friends in America are even worse than we are, and those of us who have anything to do with steam-vessels or with steamship trials, are perhaps the worst sinners. I suppose no physical problem could very well be much more complicated than that (I ought rather to say those) involved in the carrying out of a marine-engine trial at sea, especially when power and speed are both concerned. When it is considered that the final result depends on the accuracy of our knowledge of the dimensions of the steam-engine itself, and of the steam-engine indicators, on the uniform elasticity and the proper scale of the indicator springs, the accuracy with which the revolutions are observed, the accuracy of timing on the mile and of observing the distance at the same time, to say nothing of the assumption that the indicators themselves and their gear, unlike every other thing in the universe, are entirely devoid of hysteresis, it will be seen how entirely out of the question it is that the figures

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obtained, even for a single run in one direction, should admit of statement in, say, more than three figures. When to this is added the uncertainty of the method of averaging speed as between a number of runs under different conditions as to tide and wind, the matter becomes still more striking. Or, when coal and water are also to be measured, and the weighing or measuring of both, and the calibration of all the heavy apparatus used for the purpose, as well as the personal errors due to making observations of large quantities under awkward physical conditions, in a minimum of time and in the worst of atmospheres, are considered, the uselessness and indeed the actual inaccuracy of extremely minute figures become absolutely glaring. It is often convenient, no doubt, under these conditions, to work out results to four significant figures for the sake of mere arithmetical checking; but no one who has had anything to do with the matter would suppose for a moment that more than three figures were of the least importance, and the statement of results of observations in five or six figures merely causes the enemy to scoff. Let me again say here that I am not suggesting, and I do not think, that an experiment of a technical nature is unscientific because its result is only capable of expression within one or two per cent. instead of within one or two hundredths per cent. I wish only to urge very strongly that in a really scientific spirit such an experiment must be undertaken only with a distinct recognition of its limitations, and of the limitations of accuracy of result such as I have roughly indicated.

But I must claim for technical experiment that it is truly scientific work if only it be conducted with full recognition of its conditions and limitations, and not as if it were a laboratory experiment badly done—a mistake which I fear is too often made. Let it be recognised first of all that our object is generally the determination of certain facts, or quantities, or ratios, which are to be found under certain very complex conditions. As I have elsewhere said, the duty of the engineer is to recognise these conditions and deliberately to include certain of them in his experiment. The physicist has to spend much thought and trouble on the modification of conditions, which are disturbing elements in his work. All conditions which might modify his main result, or which might make it difficult for another experimenter to obtain precisely the same value for the quantity looked for, have to be either eliminated or evaluated. The conditions are his enemies, in fact. Otherwise with us, the conditions in general form part of our problem, and for many purposes the reduction of the experi-

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ment to its lowest terms, which is the object of the physicist, would not only be impossible, but would, if it could be done, make the result quite useless to us.

The determination of the efficiency of a steam-engine is, of course, a very common piece of work, and may serve as an illustration of the two different ways of approaching such a matter in connection with this question of conditions. From the physical point of view, I imagine it would be best to endeavour to reproduce the working of the much-abused Carnot cycle.[1] If this were absolutely successful it would merely give us a result which would agree with those which we can already calculate from the physical data which are in our possession, and this result would add nothing to our present knowledge, nor would it give any additional help to the designer of steam-engines.[2] But it would, if it could be carried out, be an experiment strictly physical, and following in the lines of, for instance, Joule's classical experiment on the mechanical equivalent of heat. The engineer, on the other hand, who has to work at the same problem, has to deal with it in the fashion in which it is now handled in so many engineering laboratories. He has to make himself an actual engine, in which the normal conditions of engine working—as to loss of heat by conduction, condensation, radiation, and so on—are, or can be, reproduced, and he has to make his experiments on this machine, and as nearly as possible under conditions resembling those under which engines normally do work. Then one by one certain of the conditions may be altered, so that some estimation may be made of the effect of each. So may be obtained figures as the result of *bonâ fide* technico-physical experiment, which are also in a form more or less directly applicable to engineering work.

I have just mentioned the variation of conditions one by one. This is hardly a matter which I need insist on. It is of great

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[1] I need hardly say that I do not for a moment suggest that any physicist would wish to obtain experimentally a result for which he has already given us all the constants, and which we can therefore completely obtain by calculation based on physical results already before us.

[2] I do not wish here to be understood in the least as sharing that great objection to the Carnot cycle which I know fills the breasts of some of my friends. It appears to me that it would be just as reasonable to object to the asymptote of a hyperbola or to the line at infinity! We require these limiting cases, and should get on very badly without them, and I am not inclined to say that they are useless—indeed, I think they are extremely useful—although I am perfectly conscious that they represent a state of affairs which is technically, and even physically, unattainable.

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importance even in a physical experiment, where all the conditions are simplified to the last extent; but in a technical experiment, where the conditions themselves are very complex and often not easy to grasp, it is obviously vital. It is no doubt one of the great difficulties of all technical experiment to find out exactly what the conditions are, and it may in many cases need more experience and more care to determine and define the actual conditions than it does to carry out the measurements involved in the experiment. This is a matter which will be recognised by every one who has had to do with work of this kind, but about which probably it is unnecessary to say more here. Bearing on it, however, is a matter which may fairly be mentioned, namely, the combining of the results of several technical experiments. This is often very tempting, but is always very difficult. A simple case is, for instance, the determination of the efficiency and of the economy of a steam-engine. A certain experiment may show a certain maximum efficiency; another experiment, on a more or less similar machine, but carried out at another time, may show a maximum economy. Naturally there is a strong temptation to state both maxima as belonging to the machine tested. It is no doubt possible that they may do so; but, on the other hand, without the most minute knowledge of the circumstances of the case, it is quite unsafe to assume that they do, and in this respect the difference between the general character of purely physical work and the special character of technical experiment comes into clear relief.

In fact it is much more difficult to handle rightly the results of engineering experiment, when they have been determined, than those of pure physics. It is by no means always, or obviously, easy to apply these last, at least one has known very ludicrous mistakes to occur through their misapplication. For instance, I have seen elaborate calculations based on the determination of the weight of steam used by an engine from the pressures shown by an indicator card and the measured dimensions of the engine; and quite recently I was confronted with certain supposed phenomena, which rested entirely on the assumption that a vessel of certain dimensions actually received from a steam-pipe suddenly opened to it only the weight of steam corresponding to its volume and the pressure shown by a gauge! In both cases the troublesome phenomena of condensation were entirely left out of account, and the result of a purely physical determination was applied, or rather misapplied, to a technical problem with very disastrous results. But it is infinitely more

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difficult often to interpret and to apply the results of our own experiments. For instance, let it be found that one boiler, engine, and dynamo together require the consumption of so many pounds of coal per electrical unit, how much coal per unit will another boiler, engine, and dynamo require? Put baldly in this form the question sounds ridiculous. But after all, is it any more absurd than our constant endeavour—that is, before the days of the present development of engineering experiment—to arrive at similar comparative conclusions from the, doubtless unimpeachable, figures of an engineering pocket-book? I am sure there must be many of us who can still recollect how painfully we endeavoured to make the statements of Molesworth furnish us with an answer to our own problems, and how entirely we failed to get things to fit in. I do not suggest that the fault lay with the pocket-book; the fault lay in the endeavour to correlate figures and results which in no way belonged to each other, which represented the result of experiments made under conditions quite unknown to us, but certainly varying from each other, and no less from the conditions (possibly also unknown to us) of the problem we actually were trying to work out. I dare say that many of us who have been hungry and thirsty for facts and figures during most of our lives, remember very well the joy with which, at a certain stage, we put down in our note-books any kind of experimental results of which we could hear, or of which we could obtain possession by any means, whether they related to steam-engine trials, or to girder tests, or to the discharge over weirs;—I do not say to dynamo trials, because there were no dynamos in those days! And I am sure that all of us must have suffered pain and disappointment later on when we found how extremely difficult it was to make any use of the much-valued figures that filled our pages;—they would never, somehow or other, seem to tell us just what we wanted; there was always something about them which eluded us, one particular matter of vital importance in the data, or in the result, of which we had no memorandum. The fact is that it is always extremely difficult to apply accurately the results of experiments made by others, however carefully made and however accurately described. To realise this, even in reference to purely physical work, one need only see how many pages in the "Philosophical Transactions" are sometimes necessary to describe the methods and precautions involved in a determination which has not one-tenth the complexity of such matters as we are compelled constantly to try to measure.

The one who wishes to realise to the full the difficulty of dealing

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with, that is, of applying, the very simplest kind of experimental result, I recommend the maddening task, so often lightly spoken of by those who have not tried it, of calibrating indicator-springs, and then trying to apply the results to the correction of the corresponding indicator diagrams.

The fact is that no one can usefully apply physical results who has not himself studied the methods by which these results are obtained, either by the royal road of work in a physical or technical laboratory, or by the hard and up-hill method of self-education in the making of technical experiment, without the advantage of the preliminary training which I have mentioned earlier; and hence the importance of the knowledge of how to make accurate observations, which I have insisted upon as a thing quite apart from the knowledge of the actual figures to be obtained by such observations. It would perhaps be cruel to say that no one can usefully apply physical results who has not studied the methods by which they are obtained, were it not that nowadays the possibility of such study is open to everybody. One may therefore state the truth in this matter without the fear of making anyone unhappy. I do not know whether I should be far wrong in suggesting that a certain amount, perhaps a great deal, of the very rapid improvement which has taken place in late years in engineering practice in respect to efficiency in the working of machinery, economy in the production of energy, and economy also in the use of material, has been due directly or indirectly, or both, to the growth of the habit and knowledge of experiment among the present generation of engineers. No one who is familiar with the progress in such matters as I have this evening dealt with, during the last twenty years, and has noted the extraordinary development which has taken place, can fail to be struck with it. No doubt a considerable part of this development has been due to the better general education of engineers, and particularly to the great extension of engineering literature, in which undoubtedly the engineering newspapers have played a most honourable and important part. But these general causes in themselves would not, I believe, have been sufficient if it had not been for the contemporaneous development of what I may venture to call experimental training, accompanied by a demand on all hands from inventors, manufacturers, and even from the public, for reasonably exact numerical statements in relation to everything which can be measured, instead of the vague generalities which used to pass muster as critical examination of the advantages and disadvantages of any new proposals.

I hope I need not say here that I quite recognise that an engineer's

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life is not made of experimentation, and that the work of *doing* is much higher than that of *measuring*, as it certainly is from my own point of view. But in dealing with my subject of to-night, I am, of course, bound to take up and emphasise this special aspect of engineering work. I hope that it may be considered that I have been able to justify my choice of a subject which at first might appear so limited, but which in reality may be so important, as that to which I have addressed myself this evening—the relation of physical experiment to engineering.

Mr. JOHN WOLFE BARRY said he was sure the members present would be with him when he proposed a vote of thanks to Dr. Kennedy for his very interesting lecture. He had well said that an engineer's life was not made up of experimentation; but in one way he thought it might be said that all of them in their engineering career were more or less experimenters. They were obliged to experiment in their works of construction because, as the lecturer had put it, there were certain elements of accuracy in experimental research which could not be applied with exact adaptation to the problems with which they had to deal as engineers. Dr. Kennedy had well said that the two *rôles* of experimenter and applier of the knowledge gained by experiment had more or less, in these days of specialization, to be separated; but he was sure all who knew Dr. Kennedy would recognise the fact that he, as an engineer, had seen and had placed before them in a most instructive way those elements within which experimental knowledge could be applied for the determination of engineering problems and phenomena. It was a matter of the greatest importance not to be led too far in the direction of the idea that they could gain such an amount of exact knowledge as could be applied to works of practical utility by the mere study of physical phenomena that could be dealt with accurately in the laboratory. Our fathers, in the engineering world, had been our teachers in many more things perhaps than we realised; and we had gained from their experiments, made in the earlier days when they had not the advantages of physical laboratories, that knowledge which was of the greatest use, and had come down to us almost like the multiplication table. They thus all recognised very highly the value of the knowledge gained from past ages, but they also recognised more and more every day the extreme value of those experiments of accurate scientific investigation with which Dr. Kennedy had for many years been so intimately connected.

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Not only were they all proud to hear from him the results of his investigations and of his knowledge so gained, but they were also proud of him not simply as one of the most distinguished directors of experimental research, but as an accomplished engineer who had known how to apply his knowledge in the practical work of engineering science in various ways. He begged to propose a hearty vote of thanks to the lecturer.

Mr. W. H. PREECE, Vice-President, in seconding the motion, said that after listening to Dr. Kennedy's eloquent address he was left in doubt as to which the lecturer considered entitled to the greater praise, the investigator or the engineer. It should, however, be remembered that it was as each that the lecturer had distinguished himself; and therefore as he probably did not know whether he was more distinguished as an investigator or as an engineer, it was not surprising that he should leave his audience in a little doubt on the subject. But his audience, composed as it was of engineers, could have no doubt, for they had all been brought up with the notion that an ounce of practice was worth a ton of theory; and they all remembered that the world was their laboratory. They observed and experimented on the face of nature; and those who were called every day to ask questions of nature and to receive her replies felt far more confidence in the answers they obtained than the physicist who played with an imperfect apparatus in an ill-equipped laboratory. He had been a witness in that room of two very curious illustrations of how the physicist of the past had differed from the engineers of the past. It was not an illustration of the present day; but in that hall, or rather where that hall originally stood, he had heard the most distinguished mathematician of the day assert and illustrate by models the fact that if mathematics were true, it was absolutely impossible to lay an Atlantic cable. It was an engineer who pointed out that one simple fact known to every engineer had been forgotten; namely, that a falling body in water very soon acquired a uniform velocity, whereas a falling body in air acquired an accelerated velocity. It was the simple omission of that fact that had led to such an astounding statement being made. Again, a great physicist and mathematician of his day telegraphed to the Inspecting-Officer of the Board of Trade (he did not know whether that officer was not then present) to say in commercial language, "For God's sake don't pass the Britannia Tube; it can't exist for a month." The tube still existed, and so did the Inspecting-Officer. The lecturer had made certain references to the great principle of evolution, and had alluded to "the survival of the fittest." But

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he did not mention that although the principle of evolution might have been true in engineering, it was only true in this respect, that all the improvements were guided by design, and were dependent upon human will and human power. Those who were listeners to lectures of that kind were proud to listen to words from "the survival of the fittest," to engineers who were more competent to come and teach them than others who were found in their midst. But even they would not benefit by that principle of evolution and the survival of the fittest if there were not behind them a human will or a design to select for them the particular lecturer of the evening. It was to the man whose name figured at the head of the lectures, to their Secretary, for whom they all had such an affection, and who was about to retire from them, that they owed the survival of the fittest, and the selection of those who had done so much for their pleasure and their profit.

The motion was thereupon carried by acclamation.

Dr. KENNEDY thanked the members present very much for having so kindly received his Paper, which had been written under great stress of work, and under circumstances which made it very difficult for him, as he had said, to separate his mind from the innumerable details of every-day things sufficiently to write anything of a general nature. He was very grateful to the members for the manner in which they received his contribution, and particularly to the gentlemen who had proposed and seconded the vote of thanks.

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## SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2815.*)

# "The Transport, Storage, and Manipulation of Grain."

By PERCY WILSON BRITTON, Assoc. M. Inst. C.E.

THE growth in the demand for the food supplies of the world has led in recent years to a great increase of cereal produce, and the consequent exigencies of rapid transit and handling of large quantities of grain have necessitated a corresponding development of structural and mechanical appliances and a modification of all the conditions of supply.

The chief imports of grain to the United Kingdom are from America, India, and the regions around the Mediterranean; for which countries the wheat-crop returns for 1891 were [1]:—

| | | |
|---|---|---|
| Canada | 55,735,000 | |
| United States | 611,780,000 | |
| | | 667,515,000 |
| India | 255,434,000 | |
| Australia and New Zealand | 33,874,000 | |
| | | 289,308,000 |
| | Bushels. | |
| Russia, Roumania, and Bulgaria | 274,735,000 | |
| Asia-Minor and Egypt | 48,169,000 | |
| Italy and Spain | 198,150,000 | |
| | | 521,054,000 |

While the grain produce of Russia represents 1½ bushel per inhabitant, and of India about 1 bushel per inhabitant, the produce of the American continent is equivalent to about 10 bushels per head. The census returns of cereal products in the United States for the years 1879 and 1889 show an advance of 30 per cent. during that period on the quantity (2,697,580,229 bushels) raised of the six principal kinds of produce. The most marked increase was in maize (367,481,767 bushels) and oats (401,348,555 bushels), about 90 per cent. of it being in the north central states; though the south central states show an

[1] Thirty-fifth Annual Report of the Trade and Commerce of Chicago, compiled for the Board of Trade (Chicago). Statistical Appendix; and Eleventh Census of the United States, 1890: Production of Cereals. (United States Census Printing Office, Washington.)

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increase in maize of over 69,000,000 bushels, while the chief feature of the western states is the increase of 50 per cent. in the growth of wheat. In Iowa there are over 7,000,000 acres yielding more than 200,000,000 bushels of maize; while next in order of production are Illinois, Nebraska, Missouri, Kansas, Indiana, Ohio, Texas and Kentucky, this group representing the great maize-yielding territory of the United States.

Chicago holds a central position between the lake ports and the eastern and southern outlets. Detroit occupies an equally commanding position, but its storage capacity is small on account of the through transit not requiring manipulation at this point. The resources of Galveston and New Orleans are as yet only in an early stage of development. New York is the great outlet for Atlantic shipments; and all these ports are well provided with appliances for the rapid handling of grain. At Baltimore a cargo of 98,000 bushels has been loaded in eight hours thirty-five minutes; while at Philadelphia the following speeds have been obtained:—

| | | | | |
|---|---|---|---|---|
| Port Richmond elevator | . . . | 110,053 bushels | in 8 hours | |
| Girard Point „ | . . . | 72,000 „ | 5 „ | |
| „ „ „ | . . . | 105,500 „ | 8 hours 10 minutes | |

The gigantic granaries, or "elevators," typical of the American grain-trade, are, in the main, the outcome of the accumulation or "warrant" system of supply regulated by the Boards of Trade established at all the important commercial centres.

The amount of grain dealt with in 1893 at Chicago in the "regular" elevators—those registered by the Board of Trade for State grading—was about 110,000,000 bushels; of which the Armour Company's elevators took some 34,000,000 bushels. In addition, about 120,000,000 bushels were received in cleaning-houses and mills for transfer or local consumption. The value of the crops thus placed on the market, within the three or four months following harvest, averages about £350,000,000, in movement over thousands of miles of railway and waterway; transferred from the one to the other at junction or terminal points; stored in the city elevators; or shipped into ocean vessels. About 28 per cent. of the wheat-crop and 4 per cent. of the maize is exported. These commercial necessities form the basis of the structural and mechanical developments of modern grain-trade appliances.

In India the conditions are so entirely different that no such development of storage and transfer facilities has yet been developed. The climate permits of storage in the open air during seven or

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eight months of the year without rent or fire insurance; while the extreme cheapness of labour greatly discounts the effect of machinery. Indian grain is also not well adapted for storing in bulk for any length of time. The railway systems also are not sufficiently developed to enable large quantities to be conveyed quickly to any central point; nor are large tracts of land laid down for any one class of grain which would justify sufficient centralization accommodation.

## Transport.

The consideration of transport involves the appliances for transfer of the grain between the different systems of conveyance; grain may be conveyed by train, road vehicle, ocean vessel, or by lake, river or canal vessel for inland navigation. The water highways of the United States are of great length, forming a series of lakes from west to east, and, with canals and rivers, afford continuous communication from the Western States to the Atlantic Ocean. Most of the grain is collected in the country and brought to the terminal ports such as Duluth or Minneapolis, or by railway or canal, to Chicago. From either point it is taken across the lakes to Buffalo, and then by water by way of Montreal or the Erie Canal, or by rail to New York or one of the other eastern ports. The chief elevator stations are, Duluth, Minneapolis, West Superior, Milwaukee, Chicago, Saint Louis, Buffalo and New York. The St. Lawrence route by way of Montreal, and the Mississippi route to the Gulf ports (Galveston, Velasco, Mobile, and New Orleans), are in course of development; and extensive improvements of the Erie Canal are in contemplation. A canal is also proposed between the southern end of Lake Michigan, near Chicago, and a point near Toledo on Lake Erie, a length of nearly 140 miles.

Electricity has been successfully used for traction of canal-boats on the Erie Canal. The average speed attained was about 5 miles, and the maximum 7 miles per hour, the motor towing six barges. The usual cargoes for lake and canal vessels are between 12,000 bushels and 20,000 bushels; but at Buffalo some of the vessels take 30,000 bushels, and a few even 45,000 bushels. The freight charge is about 12 cents per bushel for every 500 miles; the lake rate from Chicago to Buffalo is about $1\frac{1}{4}$ cent per bushel, elevator transfer rate at Buffalo $\frac{7}{8}$ cent per bushel, canal freight from Buffalo to New York $4\frac{1}{4}$ to $4\frac{1}{2}$ cents, and railway rate 6 cents per bushel. At New York the transfer elevators are capable of dealing with over 450,000 bushels per hour. There are thirty-one floating

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elevators, which can be towed alongside any vessel, and twenty-two fixed elevators, with a total storage capacity of 26,000,000 bushels.

In 1880 there were about 1,782 sailing vessels engaged in the American grain trade, but these are now disappearing. Among 959 vessels now employed, 616 are of British nationality, and 167 German, and 70 Belgian; while only 4 belong to the United States. The largest quantity carried in one cargo was 133,174 bushels. The present tendency is towards large vessels and large railway wagons: the standard being 1,000-bushel wagons and 100,000-bushel vessels, though the Chicago Board of Trade by-laws specify for sacked grain a normal wagon-load of 400 bushels. During the navigation season very little grain is sent by rail to the sea-ports.[1]

In the sea-going vessels bound for the United Kingdom, stringent precautions are adopted for the prevention of shifting of the grain during the roughest voyage. "The Merchant Shipping (Carriage of Grain) Act 1880" is designed to secure proper "precautions against shifting of grain cargo laden in port in the Mediterranean or Black Sea or on the coast of North America," under heavy seas or on account of careless loading or other cause. The chief provisions are that, where loose or bulk grain forms more than a certain portion of the vessel's cargo, it shall be divided by longitudinal and transverse partitions or boarding, and properly stowed or trimmed, or that a certain quantity in bags shall overlie the loose grain, so that it is impossible for any substantial alteration in the centre of gravity to be occasioned by any mischance or negligence, so as to affect the stability of the vessel. A vessel of the "Whaleback" type was constructed in 1891 at Duluth, and conveyed a cargo of 87,000 bushels of grain from the western end of Lake Superior through the lakes and the rapids of the St. Lawrence, across the ocean to Liverpool. This was the most compact and economical transport vessel yet devised.

For conveyance of grain in bulk by railway, box-wagons are requisite, and are loaded by a spout through an opening in the roof. The usual method adopted for unloading is a power-shovel; a large blade or scoop with chain or rope attachments, which, when placed in the mass of grain and drawn towards the door of the wagon, carries the grain before it and shoots it over the receiving hopper. With the Coker-Metcalf shovel, which is extensively in use for this purpose, one man can unload a 500-bushel wagon in fifteen minutes, or two men with a double machine can do the same in five minutes.

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[1] *Engineering*, vol. lii., 1891, p. 126.

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The wagons are marshalled through the siding to and from the receiving hopper by a "car-puller"—a horizontal capstan, fitted with a friction-clutch. This hauls between five and eight loaded box-wagons. The grain is shot out from the wagons into a hopper in the basement of the granary, which terminates in the "boot" of the elevator or "leg." By this the grain is raised to the upper part of the structure, and there passed through a receiving hopper and weighing-machine, whence it gravitates by fixed or flexible spouts to the vessel alongside the building, or to any other car or vehicle, or to the bins in which it is to be stored. In transfer from a vessel to a railway wagon, the grain is raised from the vessel's hold by a "ship elevator" or "marine leg," through the weighing-machine as before, and by spouts to the wagon or into the bins. The successful introduction of pneumatic elevators must of necessity effect a considerable simplification and modification of transfer processes.

## Storage.

Grain is stored in floor granaries, warehouses with open floor space, on which it can be placed either loose or in sacks, and which is available for any other description of goods; or in silo granaries, structures containing large hoppers or bins extending vertically throughout the height of the building, and in which the grain is stored in bulk. Granaries of the former type are limited simply to a predetermined working load on each floor, and require a considerable amount of manual labour to supplement any mechanical appliances that are adopted. Those of the latter type have been developed in their present form chiefly in connection with the American grain trade under the name of "Elevator," and, as hitherto constructed in Europe, constitute a reversion to the pre-historic method of preserving grain in a dry and sweet condition for long periods in closed pits or reservoirs.

In 1820 Mr. Doyère constructed a silo in which grain was kept for eight years, and in 1855, when a report on the subject was ordered by the French Government, he stated that the system greatly retarded decay.[1] Corn containing about 21 per cent. of water, and in contact with the air gave off 17 milligrams of carbonic acid per kilogram per hour, or 408 milligrams per day, while with the air excluded and at an average temperature of about 68° F., the quantity per kilogram per day was only 120 milligrams;

[1] "Conservation des Grains par l'Ensilage," by L. Doyère, Paris, 1862; and "Silos, Ensilage and Silage," by Dr. Manly Miles, New York, 1889.



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in other words, ventilation or exposure to the air caused nearly three and a half times the decomposition that attended the closed-bin system. Prof. Tyndall's experiments[1] have also conclusively proved that the entire absence of floating matter in the air checked all tendency to the development of life in a variety of substances which were readily acted upon by the micro-organisms of putrefaction, though reasserting their power of development upon admission of air. The late Mr. Pasteur further investigated the subject with similar results. The theory of the ancient store-pits, confirmed by Mr. Doyère's reports and by Tyndall's experiments, and adopted practically in all the great elevators in America, is that the grain is most perfectly preserved by the absolute exclusion of air; as, during such exclusion, none of the results of contact with the air—such as decomposition, heating or germinating—can be so rapidly developed. The theory that exposure to the air is essential, and that the grain must nowhere be beyond the reach of a continual current of air to protect it from heating, is the characteristic feature of many of the elevators in Europe. The Canada Wharf Granary, at Rotherhithe, provides an example of this construction, being built with iron bins, 41 feet high, 7 feet 3 inches square, with perforated sides and a central perforated tube, up which a strong current of air is forced by powerful fans, so that the grain is in contact with the air on all sides. The maximum thickness of the column of grain is only 2 feet 7 inches. The Author is of opinion not only that any such system of storage possesses no advantage commensurate with the costliness of the form of construction, but that the theory is faulty and the practical result unsatisfactory. Exclusion of air cannot prevent the continuance of decay in grain which is in a damp condition at the time of being stored, so that it is essential, if the grain is to be kept for any length of time, that it should be transferred in a dry condition or artificially dried before being passed into the bins. It should be occasionally aerated, this operation being perfectly simple, by transferring it from one bin to another, and is certainly advisable in preference to running any risk. Where any side of a bin is contiguous to a passage, it is not necessary to run the grain out to examine its condition, as tester-flaps can be provided, through which a grain-tester can be inserted. For millwork it is also useful to insert in the front of each hopper or bin a narrow sheet of plate glass, so that the amount of grain within can be seen at a glance. For

[1] "Essays on the Floating-Matter of the Air," 2nd edition, London, 1883.

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automatically registering the temperature of the grain at any point inside the bins, inaccessible to ordinary means of inspection, an instrument can be arranged to record the variations of temperature upon a cylinder-diagram, or to show the actual temperature upon a dial and to ring an alarm at any limit of temperature required. Spontaneous combustion is often alleged as the cause of fire, but Professor M. Maercker, in investigating several granary fires attributed to this cause through the heating of grain which had been soaked by floods, has expressed a conviction that spontaneous combustion in soaked and unthreshed grain was all but impossible.[1]

The silo system ensures the maximum utilization of space, and facilitates the storage of different kinds of grain. It is perfectly practicable by its means to keep the stocks of different dealers quite separate, and the hopper outlets can even be secured with locks; and as the system is always associated with a full equipment of mechanical appliances, loading, transferring, and all the laborious processes of manual labour are simplified to the utmost, and the comparative cost both of construction for a given capacity and of working any quantity are reduced to a minimum. The bins may be either square, hexagonal, or circular, and are generally built of wood, brick, concrete, or iron. The material depends greatly on the climate. The circular form is the strongest, but it involves considerable loss of space, while the hexagonal form requires more material and is more expensive in construction. Overlapping circular iron bands, with small interstices, may, however, be constructed as the framing to hexagonal bins finished in cement. The square bin is the most suitable for wood on account of the facility of framing.[2]

Wood appears to offer the greatest advantages. It is light, cheap, capable of yielding to inequality of pressure or settlement, a bad conductor, and hygroscopic. Its chief drawback is its inflammability. It is alleged that wood favours the development of the corn-weevil, but the insect appears also in grain stored in either brick or iron. Brick is perfectly uninflammable and a bad conductor, but it is not sufficiently hygroscopic, and occupies considerable space, besides being extremely heavy, necessitating more costly foundations. Iron, although very convenient for constructive purposes, transmits to the grain every change of temperature, and, being perfectly non-absorbent, causes condensa-

[1] *American Elevator and Grain Trade*, October 1893.

[2] Details of silo construction are fully dealt with in "The Construction and Equipment of Grain Magazines," by G. Luther, Brunswick: translation published by John Heywood, 1886.



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tion of all moisture in the grain and consequent rust and mould. Iron framing with cement facing combines good qualities of comparative lightness, economy of space, non-inflammability, and bad conductivity; its chief disadvantages are the costliness of construction and the great liability to disruption of the surface with an uneven shrinking or settlement.

Fire risks have an important bearing on the system of erection, chiefly on account of the accumulation of dust arising from the manipulation of grain. The dust arising from the several processes requires to be dealt with as quickly and as closely to its origin as possible; to be extracted from each hopper, separator, spout, or machine, in preference to merely creating an exhaust current through the whole room or building. The method adopted is to exhaust it into suitable receptacles or settling-chambers. In the earlier appliances it was considered sufficient to force the exhaust current of dust-laden air into any chimney-

*Fig. 1.*

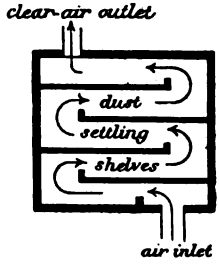
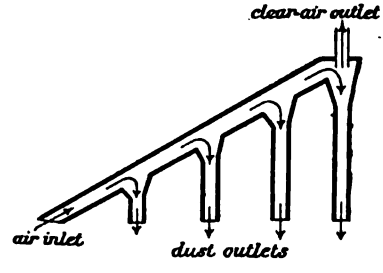



*Fig. 2.*




shaft; but this represents only part of the requirements, as the dust should be settled so as to be collected and destroyed. The simplest process is generally to draw the dust up a wooden or metal spout, by a powerful fan, and pass it into a "stive-room," or enclosed chamber, formed of wooden framing and canvas lining, where it can settle either on the floor or on a series of shelves as shown in *Fig. 1.* Where it is desired to sort the dust into different qualities, a funnel-shaped spout, with a series of outlets on its lower side, *Fig. 2*, allows the heaviest particles to drop into the first outlet, and so on, the purified air finally escaping. The positions of the openings must of course be calculated according to the vertical height to which a current of air of given velocity is found to carry the particles of given density. The "Cyclone" dust collector, *Fig. 3*, consists of a metal case in which the dust-laden air, impinging in the cylindrical head, causes a vortex movement in which the dust settles down the inverted cone,

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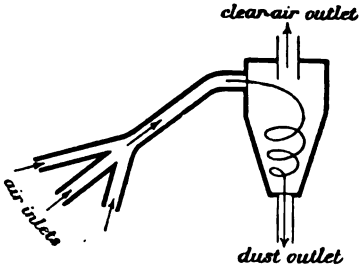
and can thence be drawn off in sacks, or can drop to any depth into a receiving chamber near the stokehole in order to be passed into the furnace and destroyed, while the clear air escapes through the vertical tube in the upper surface, the depression of the tube preventing any of the heavier suspended matter from passing upwards. Wrought woodwork accumulates less dust than rough-faced work.

All openings should be efficiently screened against sparks. Various systems of automatic floor- or ceiling-sprinklers, with plugs of alloy fusible at low temperatures, and wall-sprinklers on a similar principle, are available. Their efficiency naturally depends upon their extreme sensitiveness, accurate adjustment and accessibility; and consequently on an unfailing rise of temperature in the space enclosed. Placed in a direct and invariable air-conduit—such as in elevator or "leg" shafts or in lifts or in bins, their action may be considered as absolutely reliable; but cross-currents of air in any direction materially detract from the efficiency of the operation of sprinklers, for an outbreak of fire in such situations as mills or granaries requires to be dealt with instantaneously. Hydrants, with a double source of supply wherever practicable, and with hose suspended in an open accessible place so as to be instantly available, and with a concurrent supply of buckets and a copious renewal of water in conveniently placed tanks, are, in the Author's opinion, superior for all practical purposes to any system on which theoretical dependence may be placed to the possible detriment of actual vigilance.

*Fig. 3.*




External staircases and lifts for communication between different floors should be provided; and the hydrants should be placed as near as possible to the door on each floor, so as to be available until retreat is necessary. In large elevators it is also a safeguard to avoid long passages or traverses for shafting or belting; and separate "leg-shafts" (*i.e.*, shafts in which the elevator or "leg" is erected) are now frequently constructed, especially in connection with rope-drives. It is claimed that this system reduces the general risk by fully 50 per cent. Electric-light installations also reduce the risk as compared with open lights or with lights enclosed in breakable lamps in a dust-laden atmosphere.

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Where practicable metal lathing faced with plaster forms a useful protection to wooden surfaces. Various chemical preparations for saturating or for coating woodwork have been experimented with, but not to the Author's knowledge on the large scale of a granary fire. Their effect is to retard flame, but the substance is charred into a condition of disintegration which, in a fully loaded silo-granary, may necessitate more dangerous work in its replacement than if it had been completely burnt. An economical and efficient fireproof bin is still one of the chief points for prospective improvement. Floors and horizontal surfaces and external walls are made secure, but the internal supports are often left unprotected. This is a delusive source of weakness. Whether in open granaries or in the foundation piles of silos, the surfaces of vertical members in either wood or iron should be carefully protected.

The general structure of an "elevator" has already been described[1] by Mr. Pilkington. The top portion of the structure, the "cupola," determines the height of the building, as the grain is elevated to a sufficient height to flow into garners or storage-hoppers, the capacity of which is sufficient to ensure a constant supply to the "weighing-hoppers" or "receivers," which act intermittently, passing the grain through in given quantities, generally about 2 tons or 3 tons, to the distributing spouts or swivel shoots. Some American elevators are built with external walls of brick; but as a rule the whole structure is of wood and iron. In the United Kingdom such structures are not permitted without brick external walls. Unless an otherwise unnecessary thickness of walls is adopted, it is essential to either tie the whole structure well through, or, preferably, to make the bin framing entirely independent of the external shell.

The bins may be constructed of vertical studs with longitudinal and transverse ties and with sheathing or lining of grooved and tongued boarding; but in America, where "lumber" is plentiful, the system of "cribwork" is generally adopted, the sides of the bins being formed of horizontal layers of 2 inches by 6 inches spruce planks closely nailed together. Storage elevator bins are, in America, usually flat-bottomed and formed of 14-inch by 3-inch joists at about 9-inch centres, across which is laid 2-inch by 6-inch match-boarding. Bins exceeding about 12 feet by 16 feet are "rodded," or tied in by steel rods of between $\frac{3}{4}$ inch and $\frac{7}{8}$ inch in diameter at intervals of about 5 feet. The diameter of the rods

[1] "On the Elevation, Storage and Shipment of Grain." Minutes of Proceedings Inst. C.E., vol. lxxvii. p. 237.

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was formerly increased towards the bottom of the bin; but the horizontal pressure is practically constant below about 15 feet from the top of the bin, in all bins the height of which exceeds twice the width. It was frequently found that larger rods were bent by the weight of the grain and pulled in the washers, while the smaller rods cut through the grain. In its vertical pressure, however, the cohesion of the grain tends to bridge across the space, and to relieve what would otherwise be an immense pressure over the whole floor-area, concentrating the load upon the upright posts by which the bins are supported. The pressure upon the bottom is, however, enough in any case to cause great friction upon the outlet slides, which are necessarily of iron or steel. The Author adopts a stout pyramidal sheet-metal screen over the outlet, *Fig. 4*, with openings on each side through which the grain can pass freely without excess of pressure upon the slide. The most effective outlet under direct pressure is the segmental

*Fig. 4.*

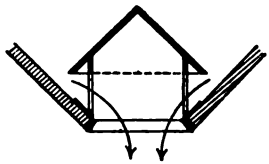
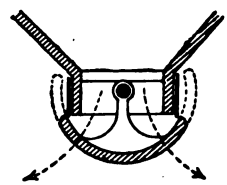


*Fig. 5.*



slide, *Fig. 5*. The concentration of load upon the posts or piers necessitates especial care in the construction of foundations, the more so as large elevators are nearly all built at the waterside on more or less yielding soil; and it is a common occurrence in America for a building to settle to the extent of several inches during the first few months after completion. The smallest inequality in settlement distorts all horizontal shafting, and, in this respect, the separate rope drives for the several legs are more readily adaptable to variation without disturbance.

The space occupied by various grains varies to a slight extent, not only for the different kinds, but in the same kind according to the conditions of storage; the height of the silos, for instance, naturally affecting the degree of compression of the grain. The average American practice is to allow 1¼ cubic foot per bushel, or 10 cubic feet per quarter (8 bushels).[1] Conversely, the number

[1] The average weight of a bushel of grain is 60 lbs.; one quarter = 60 × 8 = 480 lbs.

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of bushels contained in the bins = cubic contents in feet × 0·8. In the Liverpool silos the allowance is 11·7 cubic feet per quarter = 1·46 cubic foot per bushel; while the Author adopts for maize the allowance of 12 cubic feet per quarter = 1·5 cubic foot per bushel; and in silos less than 40 feet in height he has found it to average over 13 cubic feet per quarter. This latter figure represents the standard basis of continental practice. It may be noted that the shrinkage of grain stored for any length of time varies considerably with different qualities. The average of thirty-eight varieties, from autumn to spring, gave a reduction of nearly 10 per cent.; while some wheats average only 2½ per cent. in three years, and Hungarian wheat in the same period underwent no appreciable variation.

Elevators are classified into those for storage, for terminal, transfer and marine work, and for cleaning. Many elevators include combinations of these types. Storage elevators are designed primarily for receiving large quantities of grain to be held for indefinite periods. They are, necessarily, fitted with all appliances for receiving, distributing and delivering the grain. There are also storage elevators known as public elevators, where grain is stored for the general public. Terminal elevators combine these features with direct transfer, their essential requirements being rapid handling and shipping. They are generally "up-houses," *i.e.*, the ground floor is left open for sidings throughout and for cartage space, the bins being all constructed above the first floor, which is frequently of fire-proof construction. An elevator of this kind is fitted with all available appliances for lessening and simplifying labour. Transfer elevators require no storage capacity, or only sufficient to equalise daily variations in receipt and delivery, their function being simply to raise and deliver the grain in a consecutive process. Floating elevators are mounted on pontoons for transshipment between vessel and vessel or between vessel and land. In the marine elevator the chief feature of the transfer is the conveyance from the building to a vessel, or *vice versâ*, requiring a sufficient provision of shipping spouts and adjustable legs, so that the grain can be taken up from any depth inside the vessel's hold at varying states of the tide. Cleaning elevators are practically all "up-houses," to facilitate the movement and transfer of the stock, but they have an extra floor for cleaning machinery. In this case the grain is elevated to the upper garners, passed through the cleaners to the lower garners and thence to the bins, being mixed or blended as required. The average cost of modern

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elevators, fully equipped (on the American basis of construction), is about 30 cents per bushel, equivalent to about 10*s.* per quarter.

As previously remarked, the usual position of an elevator is at the waterside; but the precise location depends upon a variety of conditions, especially upon the arrangement of sidings, and on the general traffic on the quay. The simplest type is a building on the water's edge, *Fig. 6*, provided with ship-legs delivering into the building itself. If the elevating machinery is contained in a projecting tower, *Fig. 7*, the main building itself can be set back so as to allow space for sidings in front; or the tower may be entirely independent, *Fig. 8*, and grain delivered on to a continuous band by which it can be conveyed over any sidings, roads, canals, or intermediate buildings to the granary itself. At the South Port elevator at New Orleans, a 30-inch

*Fig. 6.*

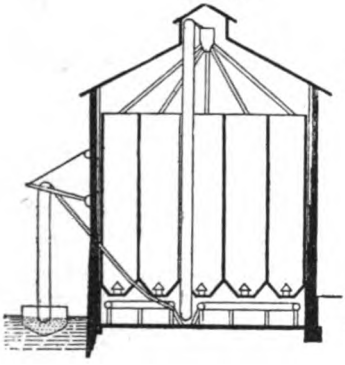
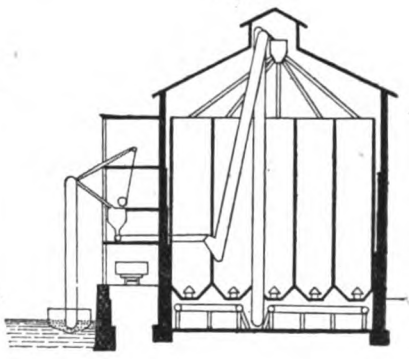


*Fig. 7.*



conveyor belt, with a capacity of 10,000 bushels per hour, traverses a distance of 700 feet from the waterside to the granary. The conveyor, instead of bridging over the surface, may be underground, *Figs. 8* and *9*. The elevating machinery may similarly be mounted in a travelling carriage, forming a travelling elevator, and conveyed to the granary in a manner similar to the latter, *Fig. 9*; or the elevator may be so arranged as to deliver into railway trucks on the sidings. The details of these arrangements will be referred to later, under the head of "manipulation."

In the United States Chicago has the largest storage capacity. The Armour Elevator Co. own seven elevators, with a total storage capacity of over 12,000,000 bushels; the Central Elevator Co. have two, storing 2,800,000 bushels; the Chicago Elevator Co. two, storing 3,000,000 bushels; the City of Chicago Grain Elevators,

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Limited, have seven, of a collective capacity of 6,000,000 bushels (including the 700,000-bushel "Galena" house, which was existing in 1857); and the National Elevator & Dock Co. two, holding 2,000,000 bushels. The new storage elevator of Messrs. Armour & Co. has a capacity of over 3,500,000 bushels. The main building measures 234 feet by 278 feet, with bins 75 feet in height, and

*Fig. 8.*

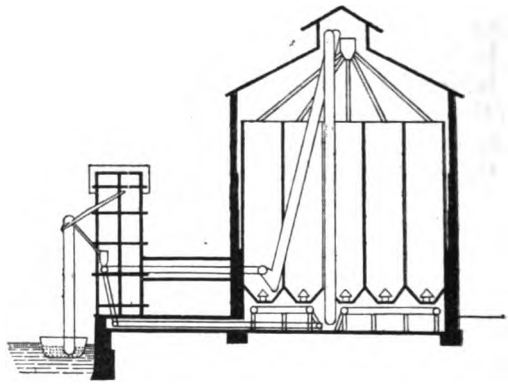
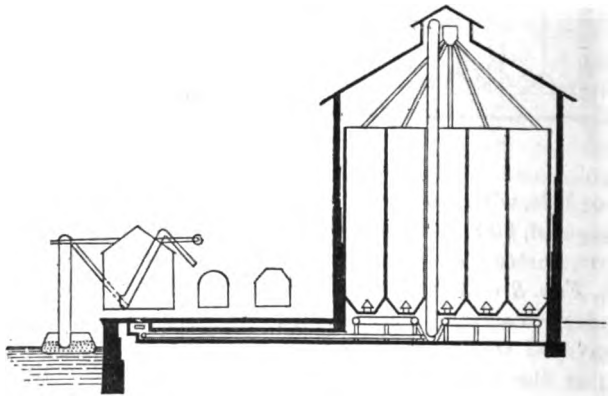


*Fig. 9.*



cupola 50 feet in height, and was erected in the phenomenally short space of thirty-two days and nights. The bins measure 18 feet by 19 feet 6 inches, and contain 8,000,000 feet of lumber. The handling capacity of the elevator is 1 per cent. of the storage, or 35,000 bushels per hour; the legs numbering twenty-eight, and the total working of all the machinery requiring 1,200 HP.

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The Minnesota Elevator, on the Ogden Canal (Chicago), has 154 bins 50 feet deep, with capacities varying between 600 bushels and 5,000 bushels. The receivers hold 1,000 bushels each. Each leg is independently driven by rope transmission, with clutch and sheave on the line shaft in the lower part of elevator. No shaft in the cupola is longer than 7 feet, and all are carried in two oscillating self-oiling boxes. The Boston Elevator, on the Boston and Maine Railroad, is 98 feet wide by 362 feet 6 inches long, has a capacity of 2,000,000 bushels, and contains eighteen legs and corresponding scales, the whole driven by two 350 HP. engines and rope transmission. In one of the most recently built elevators at Buffalo (belonging to the Eastern Elevating Co.)—a structure 185 feet by 213 feet by 162 feet high, and capable of storing 1,500,000 bushels—the system of framing is worthy of note, the load of each bin (80 feet deep) being supported on independent foundations, while the posts supporting the cupola are similarly treated, running independently right through the building to the base. Baltimore has a total elevator storage-capacity of 5,350,000 bushels, in addition to five floating elevators capable of dealing with 21,000 bushels per hour.

One of the largest elevators recently erected is at Galveston (Texas), the capacity being 1,000,000 bushels. The building measures 84 feet by 287 feet, and is 180 feet high, containing 144 bins 11 feet 8 inches by 13 feet 4 inches by 70 feet deep, with a four-storey cupola. The side cribbing is 65 feet high, and the exterior is covered with No. 24 galvanized corrugated iron. The railway wagons run into the building, and are cleared by steam shovels and fourteen elevators; while four steamers can be loaded simultaneously—the twelve spouts having a capacity of 100,000 bushels per hour. The building is fitted with fire-pumps delivering 50,000 gallons per hour, and with fire-escapes, and an installation of 1,450 Grinnell sprinklers with electric alarms, also with electric light. The total charge for switching, elevating, weighing, storing for fifteen days, and loading out, is 1 cent per bushel.

In Canada private enterprise has established a considerable number of elevators, especially in Manitoba; and the Canadian Pacific Railroad own several large structures. The first transfer point is Fort William, Ontario, on the north-west shore of Lake Superior. During the navigation season most eastward-bound grain is shipped here. Elevator A is a building 320 feet by 80 feet, constructed of timber on brick foundations. The bins, which have a total capacity of 1,250,000 bushels, are 174 in number, and

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measure 13 feet 4 inches by 11 feet ⅜-inch from centre to centre, with a total depth of 73 feet 6 inches, and are tied with 1¼-inch rods at the bottom only. The bottom timbers are 14 inches by 14 inches, and 12 inches by 14 inches, the posts being coupled 12 inches by 14 inches, and coupled 12 inches by 12 inches. The cupola contains the shipping garners and scales, and the total height is 122 feet. There are two longitudinal belt-conveyors below the bins, and rope drive is used throughout; power being transmitted also from the elevator to the annexe, which has a capacity of 1,250,000 bushels, while elevator B contains 1,300,000 bushels, a great quantity having to be stored through the winter for spring shipment. Port Arthur Elevator, holding 350,000 bushels, was the first constructed by the Company, dating from 1883. Endeavours are now being made to develop Port Arthur as a distributing point for export trade and for the general grain-market of Canada.

The next point is the eastern terminal port on Lake Huron, at Owen Sound, Ontario, where the grain is re-transferred from the vessels to the cars. The 285,000 bushel transfer elevator, built in 1883, has a handling capacity of 10,000 bushels per hour. The Toronto, Grey and Bruce Railroad Elevator is a block 122 feet 4 inches by 55 feet 4 inches by 124 feet 7 inches high from rail level. The bins are 13 feet in length, and the five rows transversely have the following clear widths, viz., two outer, each 9 feet, two intermediate, each 13 feet, and centre, 8 feet. The foundations of the main building are of rock elm, in groups of twelve piles, the fender piles being of oak. Other elevators at lake ports are situated at Goderich, Sarnia, and Kingston. The next elevators belonging to the railway company are at Montreal, where elevators A and B, both built in 1886, have each a capacity of 650,000 bushels. They are mostly used for transfer from wagons to ships. Winter storage begins on November 15th, and lasts generally till about May 15th.

Russia has various elevators, notably at Jeletz, built entirely on the American cribwork system, and containing 300,000 bushels, the Boreyscha and Maximovitch elevator at St. Petersburg (600,000 bushels), and the Odessa elevators (960,000 bushels). The latter are constructed entirely for land operation, the transport from the interior to Odessa being conducted by railway. An extensive system of "transit-silos" is proposed to be erected on a breakwater enclosing the harbour. These silos, thirty-six in number, are designed in cylindrical form, 164 feet high, 49 feet 3 inches internal diameter, and 46 feet apart (leaving spaces for the construction later of smaller intermediate silos), the whole length

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being traversed overhead by an enclosed bridge 49 feet 3 inches wide, and 16 feet 5 inches high, containing eight band-conveyors. In Bulgaria, at the port of Burgas, on the western coast of the Black Sea, a silo-granary, to hold 600,000 bushels and capable of extension to about 1,000,000 bushels, is now in course of construction. Roumania possesses two of the most completely equipped modern silo-granaries hitherto constructed, at Galatz and at Braila, both on the Danube.[1] These, like the Odessa transit-silos, were designed by Messrs. Luther of Brunswick, by whom elevators have been erected in various parts of the Continent of a total storage-capacity of 12,000,000 bushels. The bins are hexagonal, 55 feet 9 inches in height, and constructed of iron framing and cement facing on the Monier system. In addition to the above feature, these granaries are especially noteworthy for their complete system of underground conveyors, which, with the travelling and floating elevators, enable every transfer operation to be carried out with remarkable facility. At Cracow and Lemberg the elevator capacity amounts to about 220,000 bushels. At Warsaw, a portable granary has been designed and erected for military purposes. The structure is entirely of iron, and is circular on plan, about 65 feet in diameter and 80 feet high, its capacity being about 120,000 bushels. The outer columns and bracing are erected on a substantial concrete foundation, after which the circular shell, with inverted conical base and hemispherical roof, is put together. This roof contains the cleaning and weighing machinery and delivery spouts, while a central shaft contains the elevator and stairs. The grain is received at one side into a hopper, and transferred by conveyor to the elevator boot. The machinery is driven by a gas-engine. The whole structure can be readily taken to pieces and re-erected, the only necessary preparation being the concrete foundation.

The silo-granary at Budapest, on the Danube, at the central point of railway communication, possesses several features of interest. The building has a capacity of 1,200,000 bushels, and cost £187,500, the total expenditure, including quays and sidings, being about £300,000. The structure, which was completed in 1884, was designed for trading on the warrant system; but local objections considerably hampered the arrangements, each dealer preferring to keep his produce separate. The bins were originally intended to be of wood, but were constructed in sheet iron with T-iron stiffeners. Their capacities vary between 2,000 bushels and 6,000 bushels, and they are 290 in number, being erected in

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 461.

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ten groups, each with a central elevator to lift 3,200 bushels per hour. The height from ground-level to the top of the bins is 101 feet 9 inches, and the total height to the ridge of the lantern is 170 feet. The sidings and roads afford simultaneous access to sixteen railway-wagons and eight road-vehicles. The basement contains the elevator boots, the ground floor being entirely free for traffic. The next floor contains the weighing-hoppers and belt-conveyors (travelling at a rate of between 400 feet and 500 feet per minute) for distributing the grain from the bins, which are constructed above, so that all the grain is delivered from the stores by spouts. Stairs and lifts occupy the four corners of the building. The bins, which are 49 feet 3 inches deep, are constructed quite independently of the external walls, being carried on 160 wrought-iron columns, formed of riveted plates and channel-irons, *Fig. 10*. These columns are spaced longitudinally, 13 feet

*Fig. 10.*

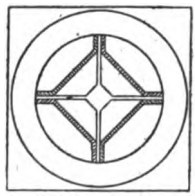
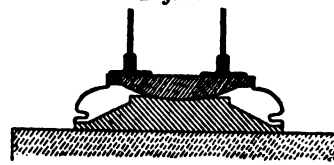


*Fig. 11.*



6 inches from centre to centre, and 14 feet 9 inches transversely, and are erected on a cup-base, *Fig. 11*, by which any inequality in settlement or any lateral movement can readily be neutralised.

Germany possesses a considerable number of silo-granaries, of which the following are the most noteworthy. That at Mannheim, holding 480,000 bushels, is of wood, and has fifty-six bins, with a lifting-capacity of 1,600 bushels per hour. Cologne granary (1) is situated 280 feet from the quay, the conveyor traversing the promenade, tramway, railway, city wall, street, and private house; its storage-capacity being 240,000 bushels; and its lifting-capacity 1,600 bushels per hour; granary (2) has a capacity of 140,000 bushels. At Uerdingen-am-Rhein also the granary (140,000 bushels) is at a considerable distance from the river, the conveyor being underground. There are granaries at Ludwigshafen (Bavaria), wood construction (660,000 bushels) at Duisburg (160,000 bushels), at Worms (in course of construction, 440,000 bushels), and at Meyer's mills,[1] Hameln-on-Weser. Amongst others

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 516.

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may also be noted those at Würzburg, Neuss (ventilated bins), Munich (120,000 bushels), Bremen, Chemnitz, Lübeck, Bochum, Treves, and Dantzig (320,000 bushels). With the special exception noted, all these silo-bins are on the closed or non-ventilated system, and all are completely equipped with elevators, conveyors, and the usual mechanical appliances. Saxony possesses no large granaries. The large mills store only on open floors, the grain being turned over by hand, but the military stores are constructed as silo-granaries. It may incidentally be noted that (as in the Warsaw example) silo-storage is especially suitable for fortresses.

France possesses few silo-granaries. The most noteworthy is at Corbeil, near Paris, with a storage-capacity of 480,000 bushels. The band-conveyor, 13·8 inches wide, passes under a public square through an iron tube 19·7 inches diameter. At Peyrehorade, Landes, on the Adour, there is a private elevator dealing with 1,600 bushels per hour. The Marseilles dock-granaries are not on the silo-system, though well equipped with elevators and conveyors, but no modern mechanical appliances exist at any of the other great French ports.

In Holland the only silos are at Middelbourg, containing 80,000 bushels. In Belgium, at Wychmael, near Louvain, the "Hungaria" granary has eighteen silos containing 80,000 bushels, while two others take respectively 64,000 bushels and 160,000 bushels. The smaller of these is an old structure, the silos being built of masonry with horizontal bottoms. The celebrated "Maison Hanséatique" at Antwerp, recently destroyed by fire, had a capacity of 880,000 bushels. The silos were erected in the courtyard of the old building, and consisted of sixty wrought-iron cylinders 14 feet 9 inches in diameter and 42 feet 6 inches high. The distribution of the grain was effected by twenty-six conveyor-belts, each 27 inches wide, and carrying 4,000 bushels per hour.

In the United Kingdom the most complete silo-granary equipment is that of the Liverpool Grain Storage and Transit Company at the Alexandra Docks, Liverpool.[1] The only reference that need be made here is to its salient features of location and construction, viz., that the bins, 250 in number, are hexagonal, constructed of brickwork 80 feet deep, having a total capacity of 2,240,000 bushels (280,000 quarters); and that the granary is at a considerable distance from the dock, the conveyors travelling

[1] "Description of the Warehouse and Machinery for the Storage and Transit of Grain at the Alexandra Dock, Liverpool," by Mr. W. Shapton, Proceedings of the Institution of Mechanical Engineers, 1891, p. 372.

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underground and traversing a large angle by a rising junction. The band-conveyors travel at a speed of between 540 feet and 600 feet, and the elevator-bands at 500 feet per minute.

At the Oldham roller-mills (Star Corn millers) there is a block, 90 feet by 40 feet, containing forty-six hexagonal brick silo-bins, each 8 feet in diameter and 50 feet deep, and having a total storage-capacity of 10,000 quarters (80,000 bushels). The brickwork is 9 inches thick. One-third of the accommodation is used for storing, one-third for distributing, and one-third for blending and mixing.

The Clarence Mills silo-granary at Hull is constructed with crib-work divisions and cast-iron hoppered bottoms. The silos, thirty-four in number, are 8 feet square and 80 feet deep. The conveyors are india-rubber belts 18 inches and 12 inches in width. The granary is fitted with weighers, separators, and steam drier, and the power is transmitted by Ewart chain driving-belts. There are smaller elevators at Bristol, Colchester, and elsewhere. With the exception of the ventilated iron bins at Rotherhithe, there are no silo-granaries of any magnitude in London. All the storage accommodation at Millwall Docks and at the Surrey Commercial Docks, where the grain-trade of London is concentrated, is in floor granaries. The North Metropolitan Tramways Company have some ventilated iron bins for about 2,000 quarters (16,000 bushels) at Bow, and similar accommodation at Kingsland; and the London General Omnibus Company have a silo-granary at Chelsea, in which the twenty bins are of wood (stud-framing and sheathing), 10 feet square, about 54 feet in clear height, with a storage capacity of 10,000 quarters (80,000 bushels), and a handling capacity of about 1,400 bushels per hour.

## Manipulation.

The several processes to which grain is subjected are:—(Primary) elevating, hoisting, or vertical transmission, and conveying, or horizontal transmission; (Secondary) weighing, separating, cleaning, mixing and sacking; and (Tertiary) bruising, grinding, or rolling.

The primary processes are essential to dealing with the grain at any stage, in any shape, or for any purpose; the second are essential to its proper storage; and the third[1] represent its utilization in the milling stage.

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[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 162–270; vol. lxxi. p. 334; and vol. xc. p. 366.

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The principle which has revolutionised all the details of storage and of manipulation is the perception that grain may be treated as a fluid, to be raised in buckets and passed through spouts and troughs in a continuous stream, and not merely as a solid, to be moved about in separate parcels. Commercial exigiencies, on the other hand, demand that grain shall be dealt with by both measure and weight.

In the United States, on its arrival at its terminal point, the grain is inspected and weighed by government officials, and assigned to certain "grades," fixed by the State, under which grade numbers it is stored. The system of "grading" was introduced at Chicago in 1858. The holder of a warrant, entitling him to draw a certain given quantity of a given grade at a certain place, is able to claim delivery accordingly from the store.

*Primary Processes.*—By combinations of vertical and horizontal transmission grain can be distributed in any desired direction. The former process, by which the grain is raised to a commanding height for distribution and storages, gives, in America, its name to the whole structure; though in Europe the term "elevator" is applied distinctively to the device for lifting the grain in a continuous succession of small instalments, without any special attachment to the hoisting appliance, *i.e.*, feeding and delivering freely and regularly, without attention or direct intervention of any operator. The elevator, or "leg," consists of an endless belt of leather, canvas, or india-rubber, or link chain, passing over top and bottom drums, pulleys, or sprocket-wheels, mounted within a rigid guide-frame; upon which belt are fixed, at suitable intervals, buckets, forks, scoops, or plates, according to the material to be dealt with. The lower end dips into or against the material to be lifted, either (as in a ship elevator) into the bulk in a vessel's hold, or, (as in a fixed elevator) into a hopper or "boot" into which the grain is poured, and which is kept sufficiently replenished for the elevator, travelling at a given speed, and taking up small quantities intermittently, to discharge the same in a practically continuous stream at the top or "head." The most suitable speeds of elevator belts, to ensure proper free and continuous discharge are:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Over pulleys 24 inches in diameter | | | = 200 feet | to | 250 feet | per minute |
| ,, | 36 | ,, | = 300 ,, | ,, | 350 | ,, |
| ,, | 48 | ,, | = 400 ,, | ,, | 450 | ,, |
| ,, | 60 | ,, | = 500 ,, | ,, | 550 | ,, |
| ,, | 72 | ,, | = 600 ,, | ,, | 650 | ,, |

Grain cups or buckets are usually of sheet steel or iron, lighter



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metal being used only for small quantities, and, when spaced 12 inches apart, will elevate the following quantities :—

| Size of Buckets. | Number of bushels raised per hour. | | |
|---|---|---|---|
| | Speed = 200 feet per minute. | Speed = 300 feet per minute. | Speed = 500 feet per minute. |
| 6 inches by 4 inches . | 275 | 412 | 687 |
| 8 „ 5 „ . | 600 | 900 | 1,500 |
| 10 „ 5½ „ . | 850 | 1,275 | 2,125 |
| 12 „ 6 „ . | 1,300 | 1,950 | 3,250 |
| 14 „ 6 „ . | 1,600 | 2,400 | 4,000 |
| 20 „ 6 „ . | 2,275 | 3,412 | 5,687 |

The casing of the elevator may be either of wood or iron, but in all instances the boot and the head are of iron. The elevator can be placed vertically, or at any convenient inclination to about 45° with the horizon, below which it would be more properly considered as a conveyor, and fitted on a different kind of framing. The usual and preferable plan is to drive from the head, where steadiness of action is necessary; and as, for convenience of dipping in the boot, a small bottom pulley is desirable, while the top pulley is of such diameter as is required for delivering the desired quantity at a given speed, the two legs of the elevator are in such case at an angle with the axis of the pulleys; though for small quantities (up to say 50 bushels a minute) no variation in diameter is required, and the two legs are therefore parallel.

For dipping in wet grain, or for exposure to weather, or for heavy loads, it is advisable to use driving-chains instead of belts; these chains being formed of separate links, with a transverse groove and clipping-bar, so that they can, at a certain outward angle, be put together or detached as required. For general driving purposes extensive use is now made of Manila or raw-hide ropes, with iron grooved-pulleys. The unequal wear of wooden pulleys induces such great strains that their use is not advisable in any situation. A tension carriage is used to take up the slack. One advantage of rope drive is that the power can be transmitted in various directions, and in positions where gearing or belting would be impracticable, and its action is not interfered with even by unequal bearings.

When the dipping point is variable—*e.g.*, where grain has to be scooped out of a vessel's hold in tidal water—the elevator is fitted

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outside the building, with a jib or pivoted arm, and either slung by chains from the point of attachment (generally the top, but varying in the upper third of the length), or with the jib prolonged to carry a counterbalance weight. The introduction of pneumatic elevators, however, seems destined to entirely revolutionise the present system of unloading. In the United States, the introduction of pneumatic power for the transfer of grain dates from about 1887, when the "Cyclone" grain-transfer barge was constructed at Cleveland by Mr. Lyman Smith, and stationed at Buffalo for trans-shipping grain from lake-vessels to canal-boats. The system has, however, attained its chief development by the introduction of the floating elevator[1] designed by Mr. F. E. Duckham, M. Inst. C.E., Engineer to the Millwall Docks Company. The elevator now in use there raises 100 tons per hour, through three suction-tubes 6 inches in diameter, each opening into a separate exhaust-chamber; whence, with most of the dust exhausted by the powerful draught, the grain is forced up or gravitates down, as the case may be, to the required point of delivery. The powerful exhaust necessary for the process requires about 2 HP. per ton raised per hour, but the efficiency and rapidity of the work performed amply compensate for this expenditure of power. The system is, of course, equally applicable from a fixed point, *i.e.*, the exhaust-chamber being fixed inside the granary, and the flexible tube extending to the vessel. The action of mechanically-geared elevators is confined to their line of sweep, and in a plane at right angles with the building at their point of attachment; while the suction-tube of the pneumatic elevator can be applied in any position or at any angle, over any intervening obstacles, round corners, or to any distance up to about 150 feet; while the whole of the heavy and complicated external framing and movable parts are dispensed with. The system is now being adopted in several parts of the world.

The transmission of grain horizontally or below an angle of about 20° with the horizon (above which slope it is seldom requisite) is best effected in large quantities or over long distances by belt-conveyors or endless bands mounted on parallel framing with top and bottom rollers at suitable intervals. In the early patterns the top rollers were inclined so as to give a grooved cross surface to the belt; but this arrangement is superfluous, as the cohesion of the grain tends to heap it towards the centre of the belt. The

[1] "Grain Appliances at the Millwall Docks," Minutes of Proceedings Inst. C.E., vol. cxxv. p. 296 *et seq.*



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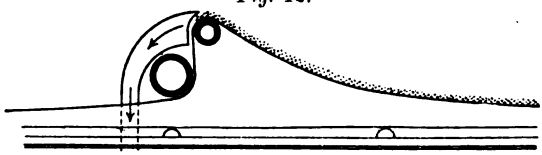
speed of belts varies between 500 feet and 800 feet per minute, and the power required is very slight. Thus, a 30-inch belt will convey 10,000 bushels of grain per hour, requiring about 1 HP. for every 100 feet of length. If grain has to be distributed simultaneously in opposite directions, the lower or return belt may also be used. The chief practical point for consideration is the delivery at any intermediate point off the lower belt, as the kipping-frame cannot be employed; but an adjustable scraper or brush enables the work to be done without difficulty. On the top or open belt the throw-off is effected by a tripper or kipper, *Fig. 12*, a travelling frame with transverse rollers, which raise the belt about 18 inches and then depress it in an S curve, so that the grain shoots over the top roller into the wide mouth of a spout by which it can be delivered to either side, while the belt itself, carried round the lower roller, continues its circuit. By throwing the rollers out of gear the friction on the belt is eased, and, the frame-clutches being loosened, the apparatus can be readily moved from one point to another.

For shorter distances or smaller quantities, a worm or screw is

*Fig. 12.*



preferable to a belt-conveyor. It requires considerably more power for working, but is compact and can deliver at any intermediate point with no more labour than the opening of a slide or attachment of a spout to the turnhead; and where frequent variations of setting are required this is an important consideration.

It is sometimes useful to record, on a different floor, the bin into which the grain is in course of delivery. This can be arranged by carrying a rod from a lug cast on the bend of the turnhead down to the required point, where a pointer will indicate on a dial or by a bell, the position of the spout above. The height of the grain in any bin may also be registered in the office by an electric indicator. The Thompson indicator consists of a small case with diaphragm side, which, pressed by the grain against a button, closes the circuit and transmits the signal. This can be fixed at any point, say at one-fourth, one-half, or three-fourths, the height of the bin, and the contents of all the bins may thus be recorded on a black-board or wall-chart in the office in any part of the building. The movement of grain in bulk upon an open floor, *e.g.*, towards a

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spout or hopper, is facilitated by the use of a power scraper or shovel, similar to the arrangement previously described for clearing out railroad-cars.

*Secondary Processes.*—It is of essential importance to have a record of the quantity of grain passed into or out of the granary, and where the weights are so considerable as to be beyond the possibilities of hand-weighing, it is additionally necessary to weigh and register the quantity passed without the intervention of any operator. The various patterns of automatic weighers in use at the present time are constructed on the same leading principles. In the Reuther-Reisert "Chronos" weigher, or in the Simon "Trent" scale, the scale proper consists of an ordinary equal-armed weighing-beam provided with a pointer; on one side is hung the grain receptacle, on the other the weight. The grain is fed in from a supply-hopper, with cut-off slide which closes when the receptacle is filled. The receptacle is mounted on knife-edges, and so long as it is not filled it is retained in vertical position by a stop or catch; but as soon as it is filled with the precise weight for which it is set, the closing of the cut-off slide releases the catch, and the receptacle tilts forward and discharges its contents; then, resuming its original position, replaces the catch and re-opens the cut-off slide. A counter with intermittent motion, recording one point with each discharge, is attached to the side of the framing. The apparatus can be adjusted to intermediate weights by a small side-lever, or the machine can be put out of action after passing any given quantity by the setting of a stop motion on a second counter.

No grain, whether direct from the fields, or from an intermediate store or from cargo, ever arrives at a granary in such condition that it does not require considerable cleaning before it can be used; to remove in the first place all extraneous objects, such as wood, stones, clods of earth, nails, twine, matting, &c.; secondly, to remove loose dust and dirt, and lastly, to cleanse the grain from any adhesive or persistent dirt.[1] The appliances chiefly used are sieves, exhaust-fans, magnets, revolving abrasion plates and cylinders, hot-air chambers, rubbers, and brushes, and may be broadly classified into: (1) Blowers and winnowers; (2) Centrifugal machines; (3) Screens, sifters and separators; (4) Graders; (5) Polishers, scourers, hummellers, havellers; (6) Clippers; (7) Washers, driers; and (8) Blenders and mixers. Several of these

[1] See also "Report on the Improvement of Indian Agriculture," by Dr. J. A. Voelcker, the special commissioner appointed by the Government.

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processes are frequently combined in one machine, so as to pass the grain through the several stages of treatment consecutively.

Winnowing belongs, strictly speaking, to treatment before reaching the granary, but on arrival it is essential to pass the grain through a receiving separator. The grain is first subjected to a powerful current of air, which cleans off the dust, while the lighter bran and scales are discharged at a separate orifice. The grain then falls on a series of shaking screens, the first of which throws off all wood, nails, clods and other foreign particles, the second screen separating coarse from fine grain, and further screens extracting all seed or sand; the grain being finally subjected to a second exhaust or aspirator, which removes any dust loosened by these successive operations. These machines are made in various sizes up to a capacity of about 2,400 bushels per hour. Wheat can also be graded according to the size of the grains by a screen of variable mesh, which is frequently combined with the separator.

The frequent occurrence of wire, nails, or small pieces of iron in the grain, makes it especially important to remove all such particles before the grain passes through the bruising-mills or rolls, not only on account of the damage to the machines and the danger to the consumer of the existence of such substances in the flour or ground grain, but because of the risk of fire or explosion with metallic particles present during the grinding. This removal is effected by passing the grain from the spout over a strongly magnetised plate of the full width of the shoot, and the reliability of the appliance is greatly increased by the use of a wiper on an endless belt traversing the magnetic plate every few moments and depositing the arrested materials in a box at the side.

Revolving cylinders, with suitable sieves and trays and separate outlets, are also used for extracting various impurities—such as seeds, cockle and clivers—from wheat, oats, or other grain. The most usual cleaning process is scouring, which may be conveniently effected in a horizontal cylinder having a series of disks, fixed on a central shaft, made to revolve at a considerable speed. Each disk has several openings, and the grain being kept in continual motion, rattling and beating the disks and finally passing through to the outlet, is very effectively cleaned, the dust being taken up by an aspirator. Another method is for the scouring-chamber, which may be either vertical or horizontal, to be fitted with blades having a rapid reciprocating motion, so that the grain is beaten from one surface to the other. The motion of the blades assists the current of air for exhausting the dust.

Dusting or polishing and removal of dirt from the crevices of

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grain may be performed by a series of stiff brushes revolving in and against the surface of a wire-gauze cylinder. To prevent the gauze from becoming clogged it is necessary to tap it frequently; this can be done mechanically by a light rapper operated by mitre-gearing.

Grain which is too heavily clogged to be satisfactorily dealt with by the above processes only has to be washed. One compact form of washer admits the grain first into a corrugated cylinder, against the periphery of which it is pressed by revolving blades, so as to pulverise any lumps of earth or clay, the dust being removed by an intermediate exhaust-fan before the grain passes to the washing cylinder. Here the grain is kept in active motion in the water, until all impurities are removed, and is then carried to a drying cylinder. Another form of washer is an inclined cylinder fitted with a screw which carries the grain from the feed at the lower end against the water, which is supplied from the upper end through a central cylinder. It is essential, after such a process, that the grain shall be thoroughly dried. This is generally effected by passing it through a chamber or cylinder containing air heated by a furnace or by steam. A central shaft carries a number of forks which are constantly revolving to prevent the grain from clogging or accumulating. Improved drying apparatus is much needed in manipulation processes, and may in this respect be considered to rank with the development of pneumatic loading and electro-motors.

Various other processes of clipping, hulling, flattening, splitting, and shelling are performed with facility by machines adapted for the respective classes of work. The packing of flour or other powdered materials is also greatly expedited by the use of a cylindrical packer, fitted with a vertical revolving shaft terminating at the lower extremity in a screw-bladed presser. The sack is drawn on outside the metal core, which relieves the canvas of any pressure during the filling, while the material itself is pressed to a considerable degree of compactness. These special processes cannot, however, be considered as essential features of general storage or manipulation, and claim, accordingly, no further detailed description.

In conclusion, the Author desires to express his acknowledgments to the many correspondents in America and elsewhere, from whom he has received courteous attention and valuable information and assistance in the preparation of this Paper.

The Paper is accompanied by four drawings, from which the *Figs.* in the text have been prepared.

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(*Paper No. 2964.*)

# "On the Construction of the Military Outport at Libau."

By DMITRI THEODOR JARINTZOFF, Assoc. Inst. C.E.

THE town of Libau, *Fig. 1*, is situated in the Government of Courland, its latitude being 56° 30′ N., and its longitude, reckoned from Pulkovo, 9° 19′ W. It is the most southern Russian harbour on the Baltic Sea, and the most western in the whole Empire. The town occupies the northern extremity of the narrow spit of sand which separates the lake of Libau from the sea. It consists of two parts, the southern (old Libau) and the northern (new Libau) (see *Fig. 3*). They lie on each side of the channel which forms the harbour, and which was excavated as early as the seventeenth century, being at the present time 350 feet wide, about 18 feet deep, and bordered by shipping quays.

The country surrounding the town is very low, its highest point above the level of the sea not exceeding 14 feet. As the land recedes from the sea and approaches the lakes of Libau and of Tosmar, it gradually becomes lower, and at the shores of the lakes it falls to 3 feet to 4 feet above the mean sea-level. The lakes, notwithstanding their great size, are very shallow. The depth of the Libau lake is between 2 feet and 3 feet, that of Tosmar between 2 feet to 4 feet. Into the lake of Libau falls the River Bartaw, navigable for 50 miles, along which timber is transported in rafts, and stone and agricultural produce in boats. To the north, between the town of Libau and the lake of Tosmar, at the distance of about 1 mile from the beach, is a line of ancient dunes, overgrown with trees. These dunes attain a height, in places, of 35 feet or 40 feet. The lake of Tosmar is united with that of Libau by a small stream. The country from the dunes inland is covered with pine forests stretching far into the interior. Skirting along the sea-shore are lines of sandy dunes, attaining in places a height of between 14 feet and 18 feet. The sea-faces of the dunes either slope gradually to the water, or, where undermined by the waves, form cliffs about 7 feet high. Below the water-level the sandy bottom sinks gradually, at a uniform slope,

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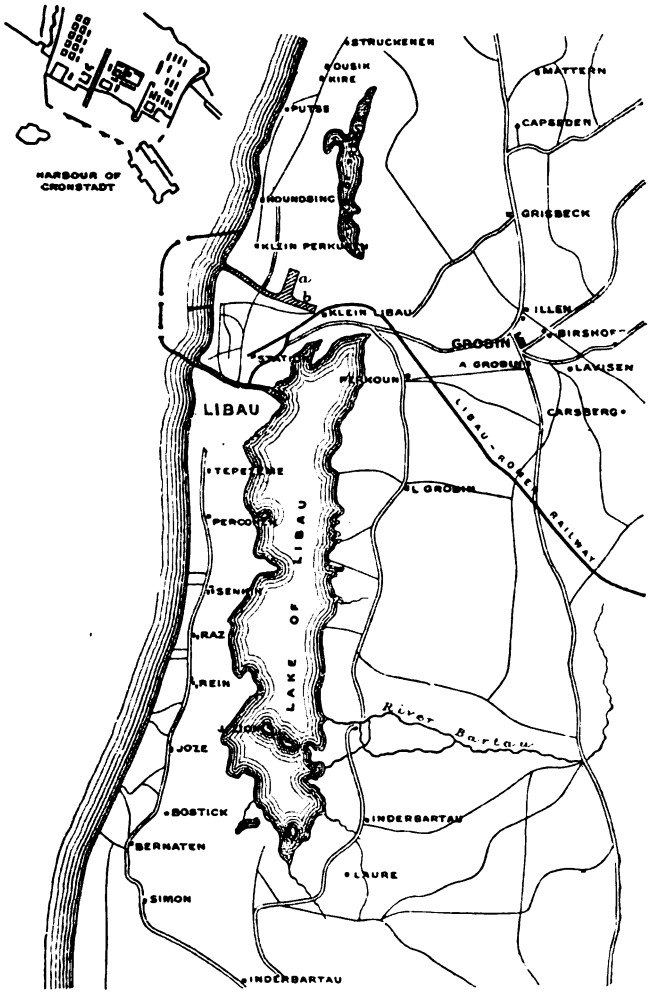
to a depth of 20 feet to 24 feet, where a narrow belt of coarse sand and gravel is met with. Farther out to sea the bottom consists of

*Fig. 1.*




Scale, 1 inch = 21,000 feet.

ENVIRONS OF LIBAU.

stiff clay, in which are imbedded a number of large boulders. A depth of 30 feet is attained at an average distance of 4,000 feet from the shore.

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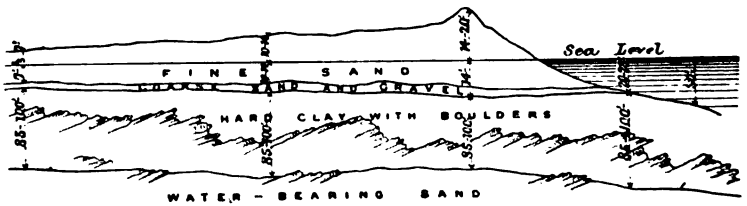
The geological structure of the country in the environs of Libau is shown in *Fig. 2.* The surface is covered with fine sand, of which the dunes are also formed. This sand is clean, very white, and so fine that it can pass through a sieve with 5,800 holes to a square inch. The sand extends along the bottom of the sea till a depth of between 20 feet and 24 feet is attained, while inland it extends to the lakes, the bottoms of which are, for the most part, covered with but a thin layer. Under the fine upper layer lies coarse sand, mixed with a variable quantity of gravel. The thickness of the coarse sand is, as a rule, insignificant, from a few inches to 2 feet to 3 feet, though in several places it attains a thickness of 5 feet to 7 feet. Under the coarse sand lies stiff blue clay, with associated granite boulders. At lower levels the clay is more sandy, and of different colours, yellow, red, and white. The different layers of clay vary from 85 feet to 100 feet in thickness. Between the greasy and the sandy clays

*Fig. 2.*




GEOLOGICAL STRUCTURE OF THE COUNTRY AT LIBAU.

are to be found some flags of limestone, the thickness of which is very variable, from 3½ feet to 28 feet and more. Thin layers of limestone are also to be met in the lower part of the sandy clay. The thickness of the rich clay over the flag is not the same in all parts of the country. It is considerable near the shore and to the south of Libau, where it sometimes attains a thickness of between 40 feet and 50 feet; but this decreases greatly to the north and north-east. Near Tosmar the layer of thick clay is not more than 15 feet, and beyond, the limestone appears in places on the surface. The rich clay, wherever it lies open, even on the bottom of the sea, is covered with a thin layer of coarse sand and pebbles derived from the erratic boulders. Nevertheless, in places the clay is not so covered, but the sand and pebbles lie in potholes in the clay, or extend in long beds. Underneath the clay there is sand, the depth of which has not as yet been ascertained. It forms a water-bearing stratum, from which Libau draws its

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water-supply by means of artesian wells. Besides the geological features described, the environs of Libau are characterised by the erratic stones, which are found all along the shores of the Baltic, and are to be met with in the interior of Russia, even as far as Moscow. They consist of granite blocks, travel- and water-worn, brought by the glaciers from Finland, and widely scattered during the Silurian and Devonian periods. The size of these erratic boulders sometimes does not exceed that of ordinary paving-stones, and sometimes the bulk reaches between 200 cubic feet and 400 cubic feet. In places they lie in masses forming wide and long beds of considerable thickness. Of such beds are formed the stone-reefs which extend along the bottom of the sea in front of Libau. The boulders furnish the only building materials in the west of Courland, and for the harbour-works they had to be collected even in the fields and brought from a distance of several miles.

The variations of the sea-level depend only on the winds, and are relatively considerable. The tide falls to 3 feet below the mean level during the prevalence of strong E. and N.E. winds; and the highest level is attained in the open sea, and reaches to between 3½ feet and 4 feet above mean level during violent storms from S.W. In the commercial harbour the water rises still higher, and once—in 1856—it attained to a height of 6 feet. But such cases are exceptional; the usual variation of level is, during the summer, 8 inches, in the spring and autumn 13 inches, and in the winter 18 inches. The level is lowest in May, and highest in December. The strongest and prevailing winds blow from the west. For one hundred and seventy-two days in the year the wind blows from S.S.W. to N.N.W.; the heaviest gales come from the S.W. Cases have been recorded when the velocity of the wind reached 80 feet per second. The S.S.W. and W.N.W. winds attain a velocity of 60 feet per second; the S.S.E., N. and N.N.E., seldom attain such force. The winds from the N. to the E. and S. prevail only from January to April. During the remaining eight months they are westerly. Under the influence of sea-winds which raise the water-level, currents, attaining at times a considerable velocity, occur along the coast. The winds from S. to W., especially S.W., produce a current from S. to N. attaining a velocity of between 1·4 mile and 1·7 mile an hour. The N.W. and N.N.W. winds produce a current of much less intensity, only between 0·6 mile and 1·0 mile per hour.

The wind, the action of the waves and of the sea-current have a continual influence on the coast line, even where the shore

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consists of compact clay, rock and stones. They act with greatest effect on the coast near Libau, which consists of fine sand. Even a slight wind moves the fine sand, and the sea-currents displace it in large masses, which are deposited again at the first obstacle, such, for instance, as a mole. The swell also assists this action, as it disturbs the sand to a considerable depth. As the strongest and the most persistent winds at Libau are those from the S.W., S., S.S.W., and W.S.W., the shifting of the coast sand is from the S. to the N. During the construction of the mole for improving the entrance of the commercial harbour, the sand collected in considerable quantities in the corner formed by the beach and the southern mole. The height of the dunes in this place has increased also, and the sand which is driven from their tops by the wind often silts up the channel at the entrance of the harbour.

Libau must be considered as the only Russian port on the Baltic Sea navigable during the whole year. If the water is ever covered with ice, it is only once in several years, and that only for a few days. According to German sources[1] the port of Libau during twelve winters—from 1857 to 1869—had been closed for sailing ships during only nine days; but for steamers it was always navigable. Russian sources do not give any certain indications about this period. From 1869 to 1887—for eighteen years—the harbour was closed for sailing ships: seven days in February, 1871, seven days in December, 1875, one day in February, 1880, and two days in February, and two days in March, 1883. It was most affected on the 21st February, 1886, when the whole visible surface of the sea was covered with ice, and navigation was closed till the 3rd March, altogether ten days. After 1887 the harbour was covered with ice only once for two weeks in the severe winter 1892–1893. It is probable that even these short interruptions of the navigation could be avoided by the use of a good ice-breaker. The tug which has been provided for the commercial harbour of Libau since 1874 is not suited for this purpose, neither by its construction nor by its power. Thanks to the high temperature of the winter months, and the continual moving of the ships in the harbour, the ice cannot get very thick; the drift ice cannot collect before Libau, because of the straight or even slightly convex coast-line. The frequent S. and S.W. winds, at a temperature, even in winter, above freezing-point, break up the ice and do not allow it to form

[1] "Segel-Handbuch für die Ostsee." Herausg. von dem hydrographischen Büreau der Kaiserl. Admiralitat. Berlin, 1883–86.

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a mass; and even when the wind blows from the E., and lowers the temperature, it at the same time drives the broken ice out to sea. Owing to these conditions, the ice floating from the north, even if it approaches Libau, does not remain there for long, seldom freezes, and soon drifts away.

Libau, as a commercial harbour, was known in the thirteenth century, and at the end of the seventeenth century works were executed for the improvement of the port, and for the formation of the inner basin. In the middle of the eighteenth century, the entrance to the harbour was surrounded by moles, but soon the depth diminished to 8 feet, in consequence of the drift along the coast. In the present century the moles have been built farther and farther out to sea, and the depth at the entrance has increased between 10 feet and 15 feet, and that in the harbour between 13 feet and 16 feet. In 1857 large works were begun for the improvement of the port. The moles were extended into a depth of 20 feet, the harbour was dredged to the depth of 18 feet, and the banks were enclosed by quays, *Fig. 3.*

About 1870, when the Libau-Romen railway was built, Libau rose greatly in importance on account of its being a winter-harbour, and numerous plans for its improvement were broached, and the following actually carried out. Between 1875-1887, the southern mole was prolonged, the wooden quays reconstructed of stone, an additional basin 22 feet deep was built, and the entrance deepened by means of new and powerful dredgers. But as the depth attained by these works did not exceed 16 feet or 17 feet, and as the extension of the quays was insufficient to meet the growing trade, in 1887 the Ministry of Ways of Communications put forward a new project according to which, besides widening and deepening the harbours, it was resolved to construct a large outport by extending the moles to the line of 30 feet depth of water. Concurrently with these projects, plans were also commenced for the construction of a military port, and eventually it was decided that the most advantageous situation would be to the north of the commercial port, to which it would be united. To carry out these designs the southern mole of the commercial port was to be prolonged into the sea, where its depth reached 30 feet, and was then to turn sharply to the north, parallel to the coast, *ab*, *Fig. 3.* On the extension of the southern commercial mole were to be placed two breakwaters, to shelter the military port from the west. The first breakwater (the southern one), *cd*, was to begin 700 feet from the head of the southern mole, and was to be 2,520 feet long; the northern breakwater, *ef*, was to be 5,250

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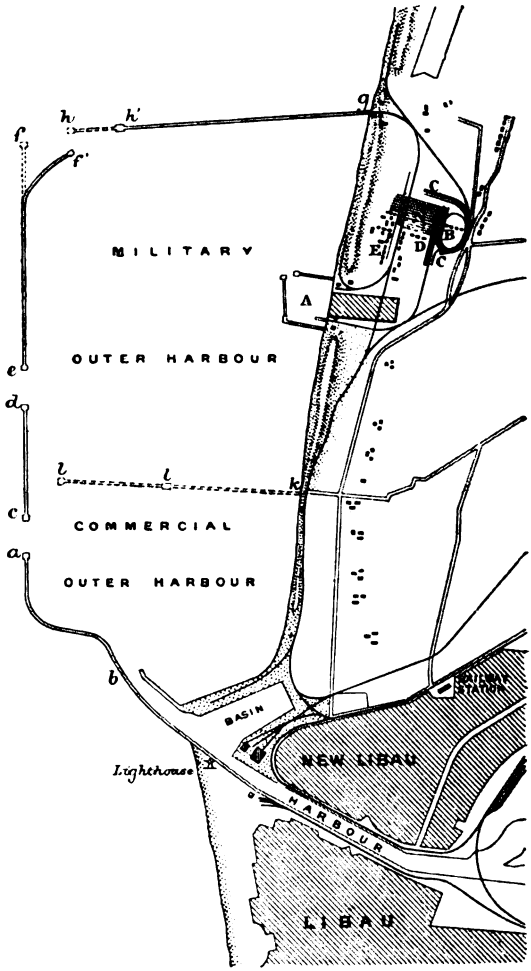
feet long, taking a straight line. For the defence of the port from the north a straight northern mole, *gh*, was provided, 6,790 feet in length. The mole, *kl*, separating the military from the commercial

*Fig. 3.*




Scale, 1 inch = 5,000 feet.

THE HARBOUR OF LIBAU.

port begins on the shore 7,770 feet from the northern mole, and runs parallel with it. It was to have been extended sufficiently far to leave a passage of 280 feet between its point and the first

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breakwater, but ultimately two alterations were made for military reasons: (1) the northern breakwater was curved at its northern point towards the shore, *ef'*, in consequence of which its length was increased to 5,523 feet, and the northern mole, *gh'*, was shortened by 875 feet; (2) the construction of the separating mole between the two harbours was stopped when its length had only reached 3,850 feet, so that a distance of 3,150 feet is left between its extremity and the breakwater, and the completion has been deferred until the position of another battery has been finally fixed upon. The military port thus forms a slightly oblique right-angled triangle, 7,700 feet long, and 7,000 feet wide, and occupies a little more than 4 square versts, or about 1,200 acres. Its natural depth is 14 feet at a distance of 1,400 feet from the coast, 22 feet at a distance of 3,500 feet, when it gradually increases to 29 feet and 30 feet as it approaches the breakwater. The port has three entrances: the first at the extreme north, the second to the west, and the third across the commercial harbour, also to the west. The width of the three entrances is the same, 700 feet. The general depth of the water seaward is 30 feet, but this is diminished in places by banks 28 feet, 26 feet, and even to 24 feet. These banks consist partly of clay and sand, and partly of beds of stones. As the deepening of the water on the banks was a matter of very great importance, the bed of the sea was inspected by the engineer-in-chief in a diving-dress. About 1 mile from the breakwaters the bottom of the sea is perfectly smooth, and not less than 32 feet deep. Only one small bank 24 feet deep is to be found, but it does not interfere with the movement of the ships entering and leaving the port.

In designing the general arrangement of the sheltering constructions of the outport two questions had to be taken into consideration: (1) to lessen as much as possible the risk of the entrances and of the interior of the port being silted up by the coast drifts; (2) to prevent floating ice from accumulating in front of the walls, and to assist the escape of the ice formed within the basin. For both purposes the design adopted may be considered as the most suitable. The movement of the sand along the coast is of a twofold character. In shallow water the sand is carried by the waves along the shore and accumulates at each exposed point, which tends to prevent its further movement. For that reason the more the southern mole of the commercial port was extended into the sea the more rapid was the growth of the coast in the angle between the mole and the shore; but in the future this growth will be slower, first, because the depth of the sea increases

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farther from the shore, and secondly, because the mole was built out at once to a considerable distance and to a great depth, which obliged the waves from the W. and S.W. to glide along the mole and dash against the coast, thus scattering the sand collected. Certainly this does not prevent the harbour from silting up, but the sand is carried for a long distance along the coast, and therefore the danger of accumulations at the entrance of the harbour is considerably diminished. Beyond the breakwater the movement of the sand is produced by the coast current, in which the particles of sand are suspended. If the currents do not meet with any obstacles the greater part of the sand is carried along the coast and is left in sheltered places, and this action is favoured by the circumstance that the breakwater and the point of the southern mole form a straight line. As regards the ice, which generally moves backwards and forwards from N. to S., the arrangement of the walls in one line is very convenient. There is nothing to stop the ice and give isolated masses time to freeze together under the influence of the cold coast winds. Consequently there can be no accumulation of large ice-masses, and a strong ice-breaker can at all times easily make a way out of the port into the open sea. The ice in the harbour, broken up by the ice-breaker, passes without difficulty through the three outlets; but this ice, owing to the mildness of the climate, is never so thick as to be a serious obstacle to the movement of the ships.

Some thirty years ago, when dredgers were still imperfect, it was difficult to preserve the necessary depths at the entrances of ports situated on an open sea-coast, either by the arrangement of the moles or by the use of sluicing-basins. Only in recent years has the improvement of dredgers and the invention of sand-pumps made it possible to neutralize the silting tendencies. The most convenient appliances for this purpose are sand-pumps, which are found to be especially suitable for dredging outside the port. By sand-pumps it is found possible to maintain the proper depth at Ymuiden, at the entrance to the Amsterdam Canal from the North Sea, and several French harbours in the English Channel are now navigable for steamers of deep draught. Although the military port is greatly less liable to silt up, on account of being sheltered from the south by the commercial port, yet there is no doubt that, even under such favourable conditions, it will not be possible to dispense with dredging at the entrance as well as in the harbour itself. This will involve periodical expense, though not of a serious nature, to judge by the experience of foreign ports similarly situated.

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The materials chosen for the walls and breakwaters were stone and concrete. Wood, in the shape of piles and cribwork, might have been used for the submerged portions, but was not adopted, as timber has become very expensive. These wooden erections are in general advantageous, and can be quickly executed in winter when the sea is covered with a thick layer of ice, but such a state of things does not exist at Libau. The stone, in the shape of granite-boulders, found in the environs of Libau, was employed to form a rubble mound for the base of the walls up to the limit of depth at which it was not liable to be disturbed by the waves. The want of boulders of sufficient size for the superstructure necessitated the employment of concrete blocks weighing between 20 tons and 30 tons. The northern mole (*Figs. 4* and *5*) was constructed of vertical walls of concrete blocks, and the breakwaters of the concrete blocks in random work (*Fig. 6*), with the exception of the heads, which were constructed in vertical walls (*Fig. 7*). The height of the northern mole above the sea-level was 10 feet, that of the breakwaters only 7 feet, in order to allow the waves to break over the top of and produce a ground swell in the harbour, not sufficiently severe to be dangerous to the shipping, but sufficient to lessen the chances of freezing. For the foundations of the walls, and for preparing the artificial blocks, it was necessary to procure about 1,000,000 tons of stone, half of which had to be broken up for the preparation of the concrete, for which also 180,000 tons of sand and about 84,000 tons of Portland cement had to be provided. These figures clearly show the extent of the works, which surpass in magnitude anything of the kind in Europe. The works were let in one contract, to compete for which only those persons were selected who had had previous experience in harbour works. The lowest price was quoted by the engineers, Messrs. Boreisha and Maximovitch, whose tender was 7·36 per cent. less than the estimated cost, and the whole price for the works, including the breakwaters and the mole, was fixed at 9,814,456 roubles. But this sum did not include the cost of the head of the southern breakwater, which had to be provided by the Ministry of Ways of Communications, although ultimately this work also was confided to the Naval Ministry, which increased the total sum to 9,905,000 roubles (about £1,050,000).

The contract was signed on the 15th May, 1890, and the date for the completion of the work was fixed for the 1st January, 1896. The contractors began with great energy and did not spare expense in providing adequate plant. At first they constructed



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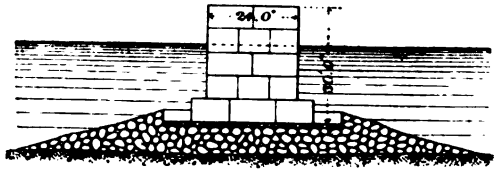
on the open beach a temporary harbour of refuge of considerable dimensions (A, *Fig. 3*). It served as a port for all the floating plant, and furnished wharves from which the artificial blocks were placed on board barges and rafts, and were then towed to the breakwaters. On the shore, a little farther from the temporary harbour, was erected a building, B, for accommodating the concrete-making machinery, driven by a 60-HP. engine. In front of it was a platform, N, for preparing the artificial blocks.

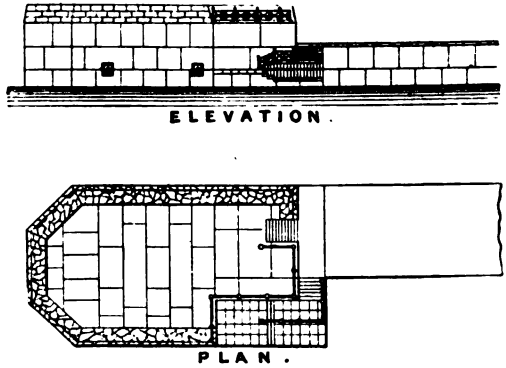
*Fig. 4.*




Scale, 1 inch = 48 feet.

NORTH MOLE. CROSS SECTION.

*Figs. 5.*




Scale, 1 inch = 48 feet.

NORTH MOLE. HEAD.

The building had twelve Messent mixers, each of which could deliver about 150 tons of concrete in twelve hours. High-level railways, C C, surrounded the building in the form of a semi-circle, and served for bringing up the stone, gravel and sand; and close to the works was built a store, D, for the cement. Between the cement-store and the temporary harbour were placed the workshops, E, stores, and dwelling-houses for workmen. Besides these works the contractors, by means of dredging and

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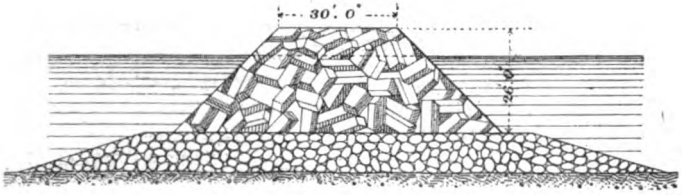
restoring walls, formed a convenient entrance into the harbour Sakkenhausen, situated 20 miles to the north of Libau, for the purpose of bringing from that locality the stone which was to be found in large quantities on the estates of Messrs. Lilienfeld and Launitz.

The general method of executing the works was as follows: The stone for the foundations of the mole and breakwaters was brought

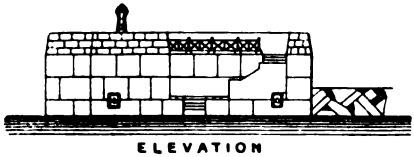
*Fig. 6*



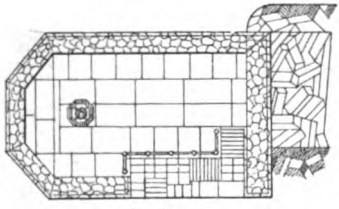

Scale, 1 inch = 48 feet.

CROSS-SECTION OF BOTH BREAKWATERS.

*Figs. 7.*



ELEVATION



PLAN

Scale, 1 inch = 48 feet.

HEADS OF THE BREAKWATERS.

from the harbour of Sakkenhausen in barges towed by steam-tugs. The barges were provided with hoppers with opening bottoms arranged to let down the stone in the places marked by buoys. The form of the rubble mound was constantly regulated by divers. The stone for preparing the artificial blocks was brought to the concrete-works by a railway 20 miles long, specially built for the purpose. This line, with its branches, entered the north of the works, and at a high level whence the stone was discharged at the



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north of the concrete-works, where it was broken by stone-breakers, which delivered it into wagons. Sand and gravel were brought in wagons from the shore to the high-level railway on the southern side of the concrete-works, and were discharged into small wagons of a definite size. The broken stone, gravel and sand were taken by horses on a narrow-gauge tramway to the building, where they were lifted by six elevators to the fourth floor, and there transferred by trams to the hoppers situated over the mixers. The casks with cement were lifted to the same floor by means of two elevators. The cement was tipped out of the casks into a large box, from which, by horizontal conveyors, it was distributed into special measuring boxes situated over the mixers. On the same fourth floor, on the top of the mixers, were gauge-tanks for water, which was supplied from two large mains, kept charged by means of a steam-pump from an artesian well. All the materials required for the concrete passed into the funnels standing on the third floor, and thence into the mixers on the second floor. From the mixers the concrete was discharged into the wagons running on a railway on the first floor. In front of the building, on the ground-level, was a large horizontal platform, N, *Fig. 3*, made of thick deals, on which rows of artificial blocks were formed in moulds of the required size and shape. In a few days the moulds were removed and the artificial blocks were left for two or three weeks to harden, after which they could be lifted and removed to the store, where they were left no less than two months to get thoroughly sound. When required for use the blocks were placed on wagons and transported to the northern mole or to the pier in the temporary harbour. Iron steam-travellers were used for lifting and removing the blocks and putting them on to wagons.

The building of the northern mole was begun from the shore, and the blocks were laid down by a Titan. The blocks forming the breakwater were deposited in two ways: (1) to a depth greater than 8 feet below the water-level by barges; (2) above that line and the surface of the water by floating cranes. The vertical wall of the heads of breakwaters was built partly by floating cranes and partly by special travellers standing on the staging. In executing the works for the breakwaters, it was found impossible to place the blocks as compactly as was desirable, so that after the calculated quantity of blocks had been used, the mound was 2 feet higher than was intended, *i.e.*, 9 feet instead of 7 feet, the reason being that, owing to the rapidity with which the works were carried out, the mound would not settle down sufficiently under the action of waves. The works

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were finished twenty-eight months before the contract time. The damage from gales during the construction, which, in similar work, generally amounts to 10 per cent. of the total value, at Libau came only to 5,365 roubles, although the value of the whole construction was more than 9,500,000 roubles. The Titan employed on the northern mole, owing to an improvement in its construction, could set down from seventy blocks to eighty blocks daily; and one traveller could lift and deliver about sixty blocks to seventy blocks. In the construction of the north mole 14,000 blocks were placed by Titan, or about 7,000 blocks yearly. The blocks weighed between 25 tons and 30 tons. The works of the harbour of Libau can only be compared with those of Dover pier and the Colombo breakwater for accuracy and solidity.

The contract sum was not exceeded. From experience gained in the construction of the military port at Libau, the following conclusions may be drawn:—

1. The cost of a mole built with vertical walls from the shore to the depth of 30 feet does not exceed 470 roubles (about £50) per lineal foot.

2. The cost of breakwaters at a constant depth of 30 feet in concrete blocks, with the heads constructed as vertical wall, is about 900 roubles (about £95) per lineal foot.

3. A mole, as well as a breakwater, can be built at a rate of about 2,800 feet a year, if adequate plant be provided. To this may be added, from experience of other harbours, that the cost per foot of basin, 30 feet deep, and 1,400 feet broad, with quays, need not exceed 1,150 roubles (about £120); and that 3,500 feet can be built yearly.

Comparing those figures with the value and with the rate of building of ironclads, the following conclusions may be drawn:—

1. The value of an artificial harbour of 1,200 acres, as, for instance, in Libau, is equal to the value of only one first-class battle-ship.

2. For the price of a single battle-ship it is possible to construct an artificial basin 1,400 feet broad, $1\frac{3}{4}$ mile long, with quays on both sides.

3. The harbour and the basin can be built even quicker than one battle-ship.

Such results are of great importance, and must be taken into consideration, when there is a question of choosing one or another point of the shore for a military harbour. In former times a ship of the line cost about 500,000 roubles (about £50,000), and was built in a few months; and harbour works cost two or three times

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more than at present, and required twice or thrice as much time for building. Therefore, the price of one artificial harbour—like that of Libau—would, fifty years ago, cost the same as forty ships of the line, that is to say, a whole fleet; and besides, the harbour could not be built in less than ten or fifteen years. In former times the construction of an artificial military harbour was decided upon only when imperatively necessary, and the enormous cost of the works, in comparison with the cost of ships, necessitated the prolongation of the works for a very extended period, as, for instance, in Plymouth, Portland and Cherbourg. The difficulty of marine works need not now form an obstacle to the construction of an artificial military harbour, if the selected position is advantageous from the strategical point of view.

The general plan of both harbours was prepared by a Marine Technical Committee in accordance with an agreement with the Ministry of the Ways of Communications.

The engineer-in-chief for the works of the military harbour was Colonel (now Major-General) MacDonald, and the assistant engineers were Captains Korsakevitch and Veselago, the engineer of the contractors being Mr. Edelheim.

The Paper is accompanied by thirty-three sheets of drawings, from a selection of which the *Figs.* in the text have been prepared.

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(*Paper No. 2958.*)

# "A Super-Elevation Tape and its Uses."

By Joseph Haywood Watson Buck, M. Inst. C.E.

In a Paper by Mr. J. Price, a formula is given for finding the length in feet of a chord, the offset from the centre of which to the rail of a railway curve gives the cant required whatever the radius may be, the length of the chord depending on the speed of the train.[1]

This formula is $\frac{V}{2}\sqrt{G}$, V being the velocity in feet per second, and G the gauge. If M is the velocity in miles per hour, the formula becomes $0{\cdot}73\ M\ \sqrt{G}$. If the ordinary gauge of 4 feet $8\frac{1}{2}$ inches between the rails be considered 5 feet between the centres of the rails of the curve, $\sqrt{G} = 2{\cdot}236$ and the formula becomes $1{\cdot}64\ M$; and a tape can be made, marked with figures representing the miles per hour alone, the reverse side being marked with similar divisions of one half the length, for convenience in finding the centre of the chord in each case.

It occurred to the Author that such a tape might be utilized, independently of the radius, in setting out a curve of adjustment between a curve and a straight line, so as to cause the super-elevation of the outer rail, by means of a regular gradient, to disappear at the junction of the curve with the straight, as shown in *Fig. 1*, indicating the construction of such a curve by means of offsets with sufficient accuracy for practical purposes. The dimensions are given in terms of the super-elevation tape and the cant, denoted respectively by S and C. Reverse curves which have been set out or laid in, without a "piece of straight" between them, may next be examined, taking first curves of equal radius, namely, which give equal cants upon the application of the super-elevation tape, as shown in *Fig. 2*. The position of a straight line corresponding to that shown in *Fig. 1* is first found by means of two offsets, each equal to four times the cant, at a distance equal to the length of the

[1] Minutes of Proceedings Inst. C.E., vol. xxxii. p. 193.

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super-elevation tape from the point of junction of the two curves, giving the first "shift" corresponding to the original curve in

*Fig. 1.*

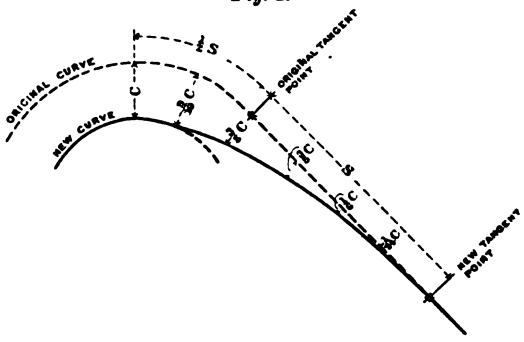
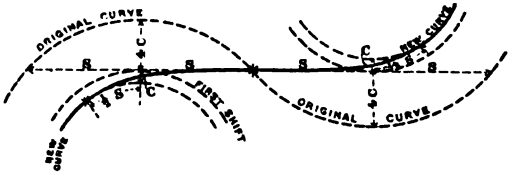



*Fig. 1.* A further "shift" is now required, equal to the cant, as shown in *Fig. 1*, and the setting out then proceeds as before, *Fig. 2*.

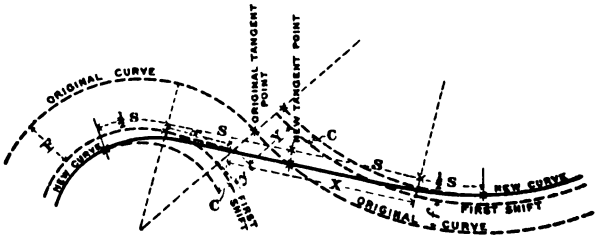
Next, curves of unequal radii, namely, which give unequal

*Fig. 2.*




cants upon the application of the super-elevation tape, as shown in *Fig. 3*, can be solved without reference to the radius of either of the curves. A straight line twice the length of the super-

*Fig. 3.*




elevation tape is required as before; and the position of this is fixed by the first "shifts," the amounts of which are obtained in the following manner:—The sum of the first "shifts" is equal to

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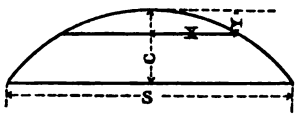
the sum of the two offsets Y and $y$, the value of each of which must first be ascertained. Let S equal as before the length of the super-elevation tape, and C and $c$ respectively equal the cants of the sharper and flatter curves. By similar triangles, the portions X and $x$ of the total length of 2 S are respectively proportional to the radii of the flatter and sharper curves; but the cants being inversely in the same proportion, $2\,S \times \frac{C}{C+c} = X$, and $2\,S \times \frac{c}{C+c} = x$, either of which being given, the other can be obtained by subtracting it from 2 S.

*Fig. 4.*




Now in *Fig. 4*, which shows the relation of the three known quantities, $c$, X, and S, to the unknown quantity Y, $\frac{\frac{1}{4}S^2}{c} = \frac{X^2}{Y}$, whence $Y = 4c \times \frac{X^2}{S^2}$. Similarly, $\frac{\frac{1}{4}S^2}{C} = \frac{x^2}{y}$, and $y = 4C \times \frac{x^2}{S^2}$.

The first "shift" for each curve is then obtained as follows, *Fig. 3*:—Let F be the "shift" for the sharper curve, and $f$ for the flatter. The "shift" in each case being proportional to the cant, and this being also respectively the inverse ratio of the offsets Y and $y$, each being proportional to the radius of its own curve, $F = Y$, and $f = y$.

The Paper is illustrated by diagrams, from which the *Figs.* in the text have been prepared.

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(*Paper No. 2923.*)

# "Transport of Live-Stock on Railways."

By the late HUMPHREY CHAMBERLAIN, M. Inst. C.E.

IN this Paper is given an account of the methods employed in working cattle traffic on the railways of the Uruguayan Republic. It is a matter of frequent occurrence in the saladero season for a train of between four and five hundred head of wild cattle to be loaded at one of the up-country railway stations, within the space of between thirty minutes and forty-five minutes; this expeditious work being effected by three or four mounted cowboys, and as many railway peons. The display of horsemanship and general smartness of the men on these occasions render the sight of loading the train a very interesting one, apart from the economic lesson in railway working that it teaches.

The wagons or vans are of the ordinary American type, so far as the bedframe is concerned. They are about 30 feet in length and are carried on two bogie-trucks. The superstructure is, however, novel in its design, and consists of two sides and a skeleton roof, with no ends; the sides being constructed and braced in such a manner as to dispense with the additional stiffness or strength imparted by the ends in a wagon of ordinary construction. The open ends of each wagon are closed, to within a distance of about 2 feet from the floor, by vertical sliding portcullis doors, which are raised by a small and simple spur-geared winch and chain attached to a cross-bar at the end of the wagon. The lowering of these doors is governed by a strap-brake with a ratchet and pawl. The lower portion of the end openings is closed by a hinged horizontal transverse flap-door, which is kept in position by catches on the lower edge of the vertical portcullis door. When the latter is raised the flap-door falls down over the buffers. The flap-doors of adjoining wagons overlap one another, and thus form a continuous floor between them. The wagons are fitted with European side buffers, or with the ordinary American centre buffer; in the latter case the flap-door is stiffened with angle-

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bars. Side doors are provided for closing the spaces between the wagons, and these hinge back and are secured against the side when travelling. For the accommodation of the attendants a footboard is fitted on each side along the whole length of each wagon and at a distance of about 2 feet from the top, or well above the horns of the cattle. These arrangements permit of each wagon being used as an independent cattle pen, of capacity to carry between twenty and twenty-five head of stock, according to the weight and size of the beasts; or of any number of wagons being formed into one continuous open pen of the required size, which can again be subdivided into separate wagons in a few minutes. The interior side-walls of the wagons are perfectly smooth, all projections being avoided in order to prevent bruising the cattle; and the floors are fitted with slats to give the animals firm foothold.

The loading-pens or corrals usually consist of two enclosures at all stations where wild cattle have to be dealt with, otherwise one corral is sufficient. The outer enclosure is made of substantial post-and-rail or wire fencing. Slip rails or gates may or may not be used at the main entrance, but guiding wing-fences are run out for some distance to direct the herd of cattle into the enclosure. A mounted cowboy at the entrance will usually suffice for keeping the cattle quiet. The inner corral communicates with the outer one by means of a slip rail, or a closed gate entrance, preferably the latter, and is of smaller dimensions than the outer one. It is constructed in a curved pear-shaped form to facilitate working the cattle round to the loading passage. The corral walls are of rubble masonry, brickwork, or close-lumber fencing, in order to prevent the animals from seeing their surroundings. Communication with the railway wagons is established by means of a gangway passage of about the same width as the wagons and rising from the level of the corral ground to that of the wagon floor and terminating in a ramp and buffer-stops at the end of the siding in which the train of wagons stands. When preparing to load the train, the cattle are driven from the outer into the inner enclosure by three or four mounted cowboys, who remain with the stock. Two peons take up their position on the top footboards of the wagons, one on each side, and two other peons stand below them on the line, one on each side of the wagons. The latter secure the side-doors of the wagon which abuts on the ramp to the corresponding latches on the end uprights of the gangway passage fence, thus making the wagon a continuation of the gangway. One of the footboard men raises the first portcullis door by the small winch gear, while the man on the

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other side stands by to assist if required. The men on the line see that the flap-door falls on the ramp, in order to form a continuous floor between the wagon and the gangway. The four men then proceed to raise and close the doors between the different cars, thus converting them into one long open pen. The doors at the end of the wagon next to the locomotive naturally remain closed. All being ready for loading, a drop-door between the corral and the loading gangway is raised. It is generally found more convenient to load the stock in sections of one wagon-load, rather than to drive the whole herd in at one time, as the latter method causes overcrowding in one part and underloading in another, thus occasioning loss of time in afterwards subdividing the animals. The cowboys therefore proceed to separate a batch of between twenty and twenty-five beasts from the herd. These animals are driven up to the gangway, and, seeing the light and open pen before them, they generally gallop through to the end wagon nearest the locomotive. When the cattle show any signs of hanging back, the top footboard peon on the offside jumps down behind them and drives them into position by shaking a rattle and shouting as he runs, and as the animals are not accustomed to seeing men on foot, this generally suffices to bring them into good behaviour. On the rare occasions when very wild or frightened cattle charge back, this man clambers up the side of the wagon to a place of safety, and it is found better to allow the animals to return and mix with the herd again in the corral, rather than lose time in forcing them to turn round. The twenty or twenty-five animals having arrived at the end wagon, the offside top attendant keeps them in position by using a short ox-goad when necessary, while the man on the other side lowers the portcullis door in a few seconds by means of the strap-brake. The men on the line place the flap-door in position, where it is secured by the catches on the falling portcullis door. The side doors are then folded back and secured in their travelling position, and the adjoining portcullis door is lowered and the flap-door raised, in preparation for the next batch of animals. The work is carried on with marvellous rapidity, and with practised hands five hundred head of stock can be loaded within half an hour. The unloading process need hardly be described, as the attendants simply place the various doors in the position for loading, when the cattle walk out of their own accord into the corral.

The system is equally applicable for tame cattle, or for horses and mules, etc., as well as for a large or small number of animals. One farmer will forward a single wagon of tame fat beasts for

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the butcher, while another will load twenty wagons of wild stock for saladero purposes. When the wagons are required for the transport of sheep or hogs, a movable centre-floor is sometimes used, which doubles the carrying capacity of the wagon, by converting it into a two-decked vehicle. In addition to the manifest economy in labour and time, the animals suffer less damage under this system than with the old plan of loading, because they are not handled, and are therefore not frightened or driven into a state of fever. It has also been observed that they are less liable to become bruised from one another's horns.

The new system has hitherto worked under the most disadvantageous conditions, in transporting the perfectly wild native cattle of the River Plate, which will not allow a man to approach them on foot. These animals are proverbial for carrying the heaviest and widest horns of any stock in the world, and are correspondingly savage; but it has not been found necessary to adopt any process of dehorning or otherwise protecting the beasts from bruising one another. With tame, or semi-tame stock, or with short-horned beasts, the advantages offered by the end-loading wagons would naturally be greater. The wagons and corrals are inexpensive in construction and compare favourably in cost with the ordinary pens and side-loading wagons. Moreover, these cattle-wagons are found very useful for the transport of lumber and general cargo, and can thus be utilized on the return journey instead of running back empty. It has been proved that an animal carried for 100 miles by rail yields more tallow and a greater weight of meat than when driven overland for the same distance, and even the hide of the train-carried beast is said to weigh between 1 lb. and 2 lbs. more. This fact, together with the absence of all loss from stampedes, drowning when crossing rivers, death from want of water or grass, accidents on the road, etc., have now convinced the breeders of the advantages offered by rail transport over the old system of driving the cattle for hundreds of miles across country. Moreover, at present, with the certainty of being able to deliver his stock at a given time, the owner is able to take advantage of the fluctuations in market prices, instead of finding himself at the mercy of the cattle dealers' ring, as he was formerly under the old system.

Although, as already pointed out, the wagons are run singly and in mixed trains, the greatest advantages are to be obtained when the cattle traffic is heavy enough to justify the running of special cattle-trains. With only a few wagons attached to a mixed train, which calls at roadside stations, the wild cattle

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are often rendered nervous, irritable and restless by the presence of passengers on the adjoining station platform, which are disadvantages avoided by a special train. The simplicity and speed of the loading and unloading process is so great that the animals can be easily fed and watered when the distance to be travelled necessitates compliance with the law governing this point.

The Paper is accompanied by eleven photographs, illustrating the system described.

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(*Paper No. 2753.*)

# "The Manufacture of Iron and Steel in Southern India."

By WILLIAM MAYLOR, M. Inst. C.E.

ABOUT a century ago, when the attention of English engineers was first attracted to the subject, Indian steel was found to possess valuable qualities, and it was even stated that for all the purposes of fine cutlery, when properly prepared it was superior to the best English cast steel. In 1818 Mr. J. M. Heath, then in the civil service of the East India Company on the Madras Establishment, being stationed in a part of India where the manufacture of steel was extensively carried on, examined the native processes and observed their defects. He concluded that if, by such imperfect means, steel could be produced which was declared by competent judges to possess the highest qualities, it was fair to infer that an undertaking for manufacturing iron and steel, from the same materials, by the most perfect European processes, ought to prove of great national importance. In 1830 Mr. Heath erected works at Porto Novo, about 100 miles south of Madras; but the means at his disposal were only sufficient to enable him to prove that pig-iron could be made without difficulty within the tropics, a result which, previously to his operations, had been pronounced impracticable. Two years having elapsed without his being able to obtain the co-operation he required, and considering the undertaking to be deserving of the encouragement of Government on public grounds, he laid the subject before Sir Frederick Adam, Governor of Madras, with a request that a Committee might be appointed to examine and report upon the results he had obtained. In consequence of the report, a Committee from the Madras Government determined on giving large pecuniary assistance to the undertaking, and extensive grants of privileges in respect to ore and fuel. Confidence having been thus established, the Indian Iron and Steel Company was formed in 1833. Furnaces, forges, and rolling-mills were erected at Porto Novo, and similar works were afterwards

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established at Beypore. In the endeavour to establish the manufacture of iron and steel in a country like India, with new materials and in such a peculiar climate, many difficulties had to be overcome, and the financial success of the undertaking was far from satisfactory. Nevertheless the Company had succeeded in manufacturing iron of very high quality which sold readily in England and India at good prices. Under these circumstances it was considered that the capital hitherto employed was inadequate to the full development of the undertaking, or to the increasing demand for the commodity for railways and other public works.

A new Company was therefore formed in London in 1853 with a nominal capital of £400,000, and operations in India were carried on with renewed energy and vigour. Two subsidiary works were erected at Poolamputty, in the Salem district, and at Trinomally in the South Arcot district, and large quantities of pig-iron of a very good quality were sent to England as ballast in cotton- and tea-ships, realising there about £7 10*s.* per ton. Owing, however, to considerable quantities of sugar and other dead-weight cargo being produced on the Coromandel coast, much difficulty was experienced in the shipment of the pig-iron to England as ballast-freight, and this, added to the repeated failures to manufacture wrought iron and steel upon a satisfactory commercial scale by the ordinary but laborious puddling process, led the Directors and shareholders to wind up the concern rather than expose themselves to the risk of further losses. Such ill success was mainly due to the difficulty of supplying the required large quantities of wood fuel, and of carrying on the laborious work of puddling and reheating on a large scale with such fuel, and in such a hot climate. Sir Henry Bessemer had just succeeded in producing iron and steel direct from crude iron by simply forcing through the molten metal powerful jets of atmospheric air (for a few minutes), and it was suggested that this wonderfully simple process was pre-eminently adapted for India. The Author was therefore instructed to report on the process as then carried on in Sheffield and in Sweden. As the Swedish works with wood fuel in some respects resembled the works in India, and with a view to minimize the cost, it was considered advisable to use apparatus on a small scale similar to that used in Sweden, especially as some portion of the machinery was already available at the Beypore Works. The experiments were attended with success.

Reports on samples of tool and spring steel which were sent to the heads of departments in Madras and Bombay were very satis-

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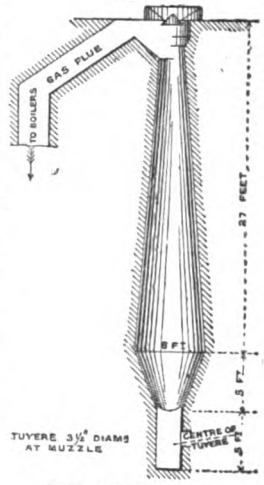
factory, and orders for supplies soon followed. The hopes of the shareholders were, however, again doomed to disappointment, as it was observed that small-sized ingots were greatly honeycombed, and when hammered out into bars numerous flaws and defects appeared, similar difficulties being met with at the time both in Sweden and in Sheffield. Larger and sounder ingots were produced, but the cost and labour of reheating and reducing them with steam-hammers to small bars proved unprofitable. Attention was then turned to the desirability of executing orders for heavier classes of work, such as rails for railways, wagon-wheel tires and axles, &c. But the Author pointed out that with wood fuel, native labour, and the heat of the climate to contend against, it was impossible to successfully compete with home manufacturers for such work, especially as costly additions, renewals, alterations and repairs were urgently required. It was therefore deemed advisable in 1864 to wind up the concern.

It may be mentioned that a foundry had also been established to use the metal direct from the blast furnaces, as well as metal (unserviceable railway chairs, old shot and shell, &c., mixed with a small portion of Scotch pig-iron) re-melted with English coke in ordinary cupolas. The extension of this branch of business was not much encouraged by the Directors, as they considered it of far greater importance for attention to be directed chiefly to the development of the wrought iron and steel trades.

A section of the blast furnaces most suitable for the ores of Southern India is shown in *Fig. 1.* Heated blast was used for a few years, but as consumers of the pig-iron preferred cold-blast iron, the hot blast was abandoned. To supply one blast furnace it was necessary to clear 1 acre or 2 acres of moderately heavy forest per day. It was eventually found impracticable to collect more than 1,500 tons of charcoal for each works per annum, equal to the production of about 750 tons to 800 tons of pig-iron for one blast furnace. About 5 tons of suitable wood were required to produce 1 ton of good charcoal, weighing 19 lbs. to 20 lbs. per cubic foot. It was advisable to use a pressure of blast equal to

*Fig. 1.*




Scale, $\frac{1}{16}$ inch = 1 foot.

SECTION OF CHARCOAL BLAST FURNACES IN SOUTHERN INDIA.



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3 lbs. per square inch (which is considerably higher than is used for blast furnaces in Austria and in Sweden) because of the small size of the ore. The cost of the pig-iron was Rs.50 to Rs.60 per ton at the port of shipment, and each furnace produced about 6 tons daily.

The iron ore which was used was a rich magnetic oxide of iron, and yielded on an average 55 per cent. to 60 per cent. of metal in the blast furnaces. It was found on or near the surface of hills in small nodules, no underground operations being necessary.

The approximate cost of the pig-iron in 1858 was as follows, exclusive of the cost of office establishment in London :—

AT PORTO NOVO.

| | R. | A. | P. |
|---|---|---|---|
| Iron ore, 1 ton 17 cwt. at Rs.9 | 16 | 10 | 6 |
| Charcoal, 1 ton 17 cwt. at Rs.10 | 18 | 8 | 0 |
| Lime (shells), 3 cwt. at Rs.2 | 0 | 4 | 6 |
| Firewood, 15 cwt. at Rs.3½ | 2 | 10 | 0 |
| Stores and renewals | 3 | 0 | 0 |
| Wages and salaries | 15 | 0 | 0 |
| Agent's commission at shipping port | 1 | 4 | 0 |
| Delivery to Madras | 3 | 0 | 0 |
| | Rs.60 | 5 | 0 per ton. |

AT BEYPORE.

There was uninterrupted water communication, and a shorter distance, between the ore ground and the works, which reduced the cost of the ore to Rs.3 or Rs.3½ per ton, and the cost of the pig-iron to about Rs.50 per ton.

AT TRINOMALLY AND POOLAMPUTTY.

| | R. | A. | P. |
|---|---|---|---|
| Iron ore, 1 ton 17 cwt. at Rs.5½ | 10 | 3 | 0 |
| Charcoal, 1 ton 17 cwt. at Rs.6 | 11 | 1 | 6 |
| Limestone, 3 cwt. at Rs.1½ | 0 | 3 | 6 |
| Firewood, 15 cwt. at Rs.1¼ | 0 | 15 | 0 |
| Stores and renewals | 3 | 0 | 0 |
| Wages and salaries | 15 | 0 | 0 |
| Delivery to shipping port | 12 | 0 | 0 |
| Agent's commission at shipping port | 1 | 4 | 0 |
| | Rs.53 | 11 | 0 per ton. |

The Paper is accompanied by a drawing, from which the *Fig.* in the text has been prepared.

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(*Paper No. 2928.*)

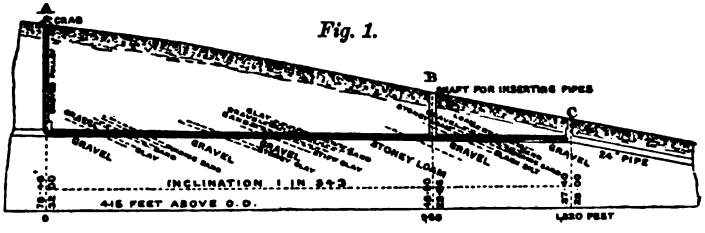
# "A New Form of Dual Drainage."

By ROBERT GODFREY, Assoc. M. Inst. C.E.

THE Author has recently had occasion to deal with a concrete sewer lined with pipes 21 inches in diameter, which admitted a considerable quantity of infiltration-water. Repeated gaugings indicated its most faulty portion to be a length of 1,320 feet, *Fig. 1*, laid in a bed of gravel and running sand, 10 feet deep at one end and 54 feet deep at the other, and constructed in a straight tunnel with a gradient of 1 in 343. The length is provided with several vent shafts, and has a manhole at each end.

A carefully timbered shaft, 16 feet long by 6 feet wide, by

*Fig. 1.*




Horizontal scale, 430 feet = 1 inch.
Vertical „ 80 „ „

LONGITUDINAL SECTION OF FAULTY SEWER.

18 feet deep, was sunk at a point, B, 968 feet from the upper end of the sewer. When the sewer was reached the upper half of the earthenware pipe and concrete were removed. A length of tramway cable, sufficient to reach throughout this length, up the manhole, A, 54 feet deep, and round the drum of a double-action crab, passing over a grooved pulley at the bottom of this manhole, was drawn completely through from the surface at A to the shaft at B. A collar of malleable iron, on which were cast two metal runners, *Fig. 2*, to fit the arc of the 21-inch pipe, was fastened on to a wrought-iron pipe (on the surface) by the ordinary method of caulking with lead. Other pipes, in lengths



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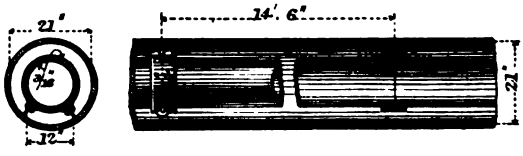
of 14 feet 6 inches, 12 inches in diameter and $\frac{3}{16}$ inch thick, each one having a collar attached, were then lowered down the shaft and the cable threaded through them one by one. The end of the cable was attached to an iron bar which crossed the end of the last pipe, and two men at the crab at A began to draw the cable and pipes into the sewer against the gradient, 1 in 343. To the leading end of the first pipe runners were attached to protect the invert of the larger pipe and to facilitate the progress of the pipes. The pipes were without flanges or sockets, but the special collar referred to was designed to make a satisfactory joint. The cable was then drawn back into the temporary shaft and threaded through another pipe, after it had been jointed to the preceding one. There was thus no tension on any joint, each succeeding pipe pressing against the joint of that preceding it. This operation was repeated till the whole length of 968 feet was inserted. After a few weeks' experience, the men engaged

*Fig. 2.*




Scale, 1 inch = 4 feet.

DETAILS OF IRON PIPE.

were able to insert five or six pipes per day. The total weight drawn on the insertion of the last pipe of the 968 feet was nearly 14 tons.

The sewage from the district above the shaft A was intercepted while the work of jointing was carried on, after which it was released and flowed in its usual course. The portion of the sewer between B and C, with the gradient, was 352 feet in length, and the same method of jointing the pipes was adopted; but owing to the excellent invert of the original sewer the men were able to push the pipes along with an iron bar acting as a lever of the second order. Both lengths of the sewer having been successfully lined, there remained only the connection of the two portions. The insertion of the iron pipes having been completed, observations were made as to whether any leakage arose within them, but they were found to be perfectly dry.

The sewage from above A was then turned into the iron pipe, as shown in *Fig. 3*, all the infiltration-water made between A

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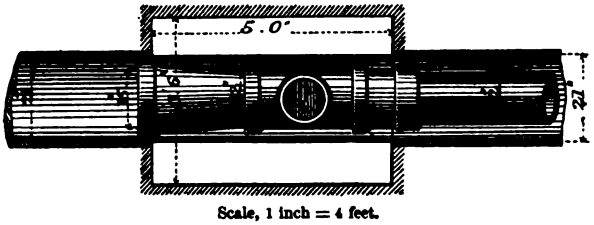
and C passing under the iron pipe and appearing in the manhole at C, side by side with the sewage. Gaugings of this clear water showed that more than 30,000 gallons per day penetrated into this part of the sewer.

The annular space between the iron and earthenware pipes at C, *Fig. 1*, was eventually filled with clay first and then concrete for a depth of 3 feet, and all the infiltration water was thus confined to its original bed.

A vertical pipe was inserted in the ground near C for the purposes of observation as to the height of this ground water.

Another length of the sewer above this length was treated in the same way with similar satisfactory result.

*Fig. 3.*




Scale, 1 inch = 4 feet.

PLAN OF MANHOLE AT A, *Fig. 1.*

The cost of the work is shown in the following Table:—

| | £. | s. | d. |
|---|---|---|---|
| 1,320 feet of 12-inch wrought-iron pipe $\frac{5}{16}$ inch thick, £6 10*s.* per ton . . . . . | 91 | 5 | 0 |
| 92 collars at 4*s.* 6*d.* each . . . . . | 20 | 14 | 0 |
| 17 cwt. of lead at 11*s.* . . . . . | 9 | 7 | 0 |
| Yarn . . . . . | 1 | 10 | 0 |
| Labour . . . . . | 71 | 13 | 5 |
| Hauling . . . . . | 1 | 17 | 6 |
| Total . . . . | 196 | 6 | 11 |

Equal to 8*s.* 11*d.* per yard.

The time occupied was from the 1st July to the 26th September, 1895, considerably more than it would have been but for the delay in obtaining the collars. The analyses given in the Appendix prove that the infiltration-water separated from the sewage is absolutely pure, thus confirming the opinion that the iron pipes are perfectly jointed.

The Paper is accompanied by a drawing from which the *Figs.* in the text have been prepared.

[APPENDIX.

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# APPENDIX.

THE following analyses of the filtration-water prove the complete separation of the sewage from the water :—

THE CLIFF, HIGHER BROUGHTON, MANCHESTER.
*Oct. 1, 1895.*

DEAR SIR,—The following is the analysis of the water called filtration-water, Belle Walk sewer :—

| | Grains per Gallon. |
|---|---|
| Total solids at 212° F. | 20·0 |
| Mineral solids | 6·0 |
| Loss on ignition | 14·0 |
| Chlorine | 2·24 |
| Oxygen for three minutes | 0·02 |
| „ for four hours | 0·10 |
| Free ammonia | 0·0028 |
| Albuminoid ammonia | 0·0056 |

I consider this to be a very 'good water, which might be used for domestic purposes, and it is quite equal to many town supplies in England.

(Signed) J. CARTER BELL, A.R.S.M., &c.,
*County Analyst.*

SALFORD SEWAGE WORKS.
*Oct. 1, 1895.*

Below is the analysis of the filtration-water taken by me from the Belle Walk sewer :—

| | Grains per Gallon. |
|---|---|
| Total solids at 212° F. | 20·5 |
| Mineral solids | 6·0 |
| Loss on ignition | 14·5 |
| Chlorine | 2·25 |
| Oxygen for three minutes | 0·02 |
| „ for four hours | 0·10 |
| Free ammonia | 0·0025 |
| Albuminoid ammonia | 0·0056 |

The above water is very good, and is better for drinking purposes than most corporation waters.

(Signed) A. P. HOPE, M.P.S., F.C.S.

To Mr. ROBERT GODFREY,
*Surveyor to King's Norton District Council.*

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# OBITUARY.

ANDREW DUNCAN CAIRNS, third son of the late Mr. James Cairns, of Dollarbank, Dollar, N.B., a well-known sheep farmer, was born at Lornshill, Clackmannanshire, on the 28th of September, 1850. After being educated at Dollar Institution, he was apprenticed in 1868 to Mr. William Johnstone,[1] Engineer to the Glasgow and South Western Railway Company, with whom he remained two years, and afterwards for a similar period to Messrs. R. B. Bell[2] and D. Miller,[3] under whom he was engaged on the designs for the new docks at Cadiz and for a graving dock and basin at Glasgow for the Clyde Trustees. From March, 1874, to July, 1877, Mr. Cairns assisted Mr. J. Watt Sandeman in the design and construction of two large ship locks on the River Weaver Navigation, having entire charge of the carrying out of the works without a contractor, which he did in a most satisfactory manner.

In April, 1878, Mr. Cairns was appointed assistant to Mr. Philip J. Messent, Engineer to the Tyne Improvement Commissioners. He was at first employed in the preparation of drawings, under Mr. Messent's direction, for the lock and entrance gates of the Albert Edward Dock, and afterwards for the tidal landing-stages on the Tyne Piers, the construction of which he superintended. In 1880 he had charge, as Resident Engineer under Mr. Messent, of the construction, without a contractor, of the piers or breakwaters at the mouth of the Tyne, an undertaking of extreme difficulty, in the course of which he displayed great readiness in devising expedients for the execution and protection of the work. In August, 1892, Mr. Cairns had an attack of paralysis, from which he apparently recovered and was able to resume his duties for some time. At the end of 1894, however, repeated attacks had so enfeebled him that he was obliged to retire, to the great regret of his employers and colleagues. He left Tynemouth and resided with his mother at Balquharn, Menstrie, where he died on the 7th of May, 1896.

Mr. Cairns was elected an Associate Member on the 5th of December, 1882, and was transferred to the class of Member on the 15th of March, 1887.

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[1] Minutes of Proceedings Inst. C.E., vol. lxii. p. 354.
[2] *Ibid*, vol. lxxv. p. 293. [3] *Ibid*, vol. xcvi. p. 322.

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THOMAS CARRINGTON, born on the 5th of October, 1841, was the eldest son of the late Mr. Thomas Carrington, J.P., of Holywell House, Chesterfield. After studying for three years under Dr. Ashby, with a view of obtaining a thorough knowledge of chemical analysis, he was articled in 1859 to Mr. J. T. Woodhouse,[1] who was in practice as a civil and mining engineer at Derby and in Westminster. He remained eight years with Mr. Woodhouse, during which period he was practically engaged in all branches of mining, including the construction of colliery railways and tramways, the sinking of shafts and the erection of machinery. In 1865 he proceeded to Nova Scotia, where he surveyed and superintended the laying out of a railway.

It was in 1866 that Mr. Carrington began to practise on his own account, in which year he sank to and eventually proved the Barnsley seam of steam coal on the estate of the Duke of Leeds at Kiveton Park, near Sheffield, and during the rest of his life he was associated with opening out and developing extensive and important collieries at Kiveton Park, West Kiveton and elsewhere. He was also for some years a partner in the Wingerworth Ironworks, near Chesterfield, and was occupied in the development of large copper mines at Bratsberg in Norway. In 1873 he was appointed by the Home Office one of the three examiners in the district of Yorkshire of candidates for certificates of competency as managers of mines. Mr. Carrington was one of the most prominent mining engineers in the Midlands, having been engaged for thirty years as umpire, arbitrator or otherwise in disputes between railway and canal companies and colliery owners, and his ability and sound judgment in highly technical cases were widely recognised. He was specially retained by the Midland Railway Company to advise on questions relating to its large mineral traffic.

Mr. Carrington had been in failing health for more than twelve months before his death, which took place at his residence, Sharrow Hurst, Sheffield, on the 27th of June, 1896. In spite of the disputes which seem inseparable from the coal-mining industry, his relations with the workmen at the Kiveton Park Collieries were always of a cordial nature, and he and his wife took great interest in the extensive schools provided by the Company for the miners' children. Mr. Carrington was elected an Associate on the 3rd of May, 1870, and was transferred to the class of Member on the 15th of January, 1878.

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 322.

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DAVID CUNNINGHAM, born in Dundee on the 14th of July, 1838, was the son of the late Mr. John Cunningham, who for many years carried on the business of a wine merchant in that town. He was educated first at the Dundee High School and subsequently at the Queen Street Institute, Edinburgh, after which he served an apprenticeship of five years to Messrs. B. H. & E. Blyth,[1] of Edinburgh. That firm was at the time engaged in railway work of a varied and extensive character, and Mr. Cunningham did not fail to take advantage of the opportunities thus put in his way of obtaining a practical knowledge of that branch of the profession. So energetic and intelligent did he show himself that eight months before the expiration of his articles he was appointed Assistant Resident Engineer on the construction of the Portpatrick Railway, on which he was occupied for nearly four years. He then acted until July, 1866, as Resident Engineer on the Galashiels and Peebles line, now part of the North British system.

Railway enterprise in Scotland becoming at that time somewhat stagnant, Mr. Cunningham found himself thrown out of employment. He made, however, good use of this enforced leisure by visiting France, Switzerland and Italy, where he considerably extended his professional knowledge. He returned to Dundee in 1867 and commenced to practise on his own account. Two years later Mr. Cunningham was appointed Engineer to the Dundee Harbour Trust, which post he held for the remainder of his life. One of his first duties was in connection with the question of dredging the river in front of the entrance to the docks. His recommendations being adopted by the Trustees, he succeeded in a few years in lowering the bed of the river 10 feet opposite the harbour walls. He next constructed a large graving dock, built extensive sheds and laid the system of rails. Other improvements followed, including the introduction of hydraulic machinery and the construction of wharves to enable vessels of deep draught partly to discharge their cargoes and enter the docks without delay. He also constructed the Cattle Depôt and wharves at Carolina Port, and took great interest in the management and working of the Tay Ferries. He invented a floating caisson for use at dock entrances, made various improvements in the construction and working of swing bridges, and devised an automatic tramway system for unloading ships' cargoes.

[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 556.

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In addition to his duties at Dundee, he superintended the construction of the harbour of Buckie, Banffshire, and he found time to make several contributions to engineering literature. In 1884 he presented to the Institution an "Account of Shifting one of the Lighthouses at Buddonness, near Dundee Harbour"[1]; and ten years later a Paper entitled "The Estuary of the Tay,"[2] in which he embodied the results of an elaborate survey of the currents and sandbanks in that estuary. For the latter he was awarded a Telford Premium. Mr. Cunningham was also the author of a volume of "Tables for Facilitating the Calculation of Earthwork"; and of an inquiry into the material and moral position of the populations of Europe and America under the title "Conditions of Social Well-being."[3] He took much interest in the progress of technical education, and encouraged the study of science and art in Dundee by the offer of medals and prizes for competition. He was elected Member on the 1st of February, 1876, besides which he was connected with the Royal Society of Edinburgh, the Royal Meteorological Society and the Statistical Society.

Mr. Cunningham died at his residence in Newport, near Dundee, on the 13th of June, 1896. For some time he had been suffering from an incurable malady, and for several months it had been apparent that his strength was rapidly failing. By his death, at the comparatively early age of fifty-seven, has been removed an engineer who was well known throughout the east of Scotland and who was identified with the extensive growth of Dundee Harbour during the past quarter of a century.

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JOHN HENRY DAVIS, born on the 24th of December, 1837, was the son of the late Mr. John Griffin Davis, of Clapham. He commenced his engineering career at the age of fifteen, when he entered the locomotive works of the London and North Western Railway Company at Crewe. There he remained four years, after which he was engaged for twelve months in the Locomotive Department of the London and South Western Railway. He then entered the drawing office of Messrs. Neilson & Co., of Glasgow, and after spending eighteen months there passed into the employment of Messrs. Sharp, Stewart & Co. in 1859. Mr.

[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p. 347.
[2] *Ibid*, vol. cxx. p. 299.
[3] These works are in the Library of the Institution.

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Davis remained with that firm until 1872, and during ten years of that time he was manager of the design department. He was next for five years manager to Messrs. Nasmyth and Wilson, and while there a 100-ton steam-hammer was made under his supervision, subsequently erected at Woolwich Arsenal under his personal care.

In 1877 Mr. Davis left Patricroft and established himself in London as a Consulting Engineer. During the following sixteen years he was engaged upon work of a varied character, for the Majorca Railway Company, the Salt Company of Ibiza and the Flour Mills Company of the Balearic Islands. He carried out under difficult conditions the narrow-gauge railways in the Island of Majorca and also large flour and jute mills, together with the necessary water-supply. For some years he acted as Consulting Engineer and Agent in London for the Egyptian Railway Administration, and was rewarded by the Khedive with the Order of the Medjidieh for his services in connection with the railway during the last war in Egypt. About the year 1893 Mr. Davis unfortunately developed brain trouble and from that time he was obliged to retire from active work. He died at his residence, Albert House, Sutton, Surrey, on the 20th of February, 1896. Mr. Davis was elected a Member on the 7th of March, 1882.

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ELIAS DORNING, born on the 25th of January, 1819, was articled to the late Mr. William Benson, of Bury, in 1836. After serving a pupilage of five years, he was engaged from 1841 to 1843 as Resident Engineer on the Bury Waterworks. Mr. Dorning then commenced to practise on his own account in Manchester as a civil and mining engineer, surveyor and land agent. He became connected with many large works during the early stages of railway development, including extensive Parliamentary surveys and valuations of properties involved, and rapidly extended his business. He was associated with Sir Thomas Bouch[1] in the purchase of land for the Eccles, Tyldesley and Wigan branch of the London and North Western Railway, and he performed similar work for the North Union Railway, the Cheshire Lines Committee and the Wirral Railway Company. He acted as surveyor for the Lancashire and Yorkshire Railway until that Company appointed a permanent surveyor on its staff. He again

[1] Minutes of Proceedings Inst. C.E, vol. lxiii. p. 301.

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acted for the Company, however, in connection with the purchase of land for the Manchester, Swinton and Hindley line to Wigan.

As a consulting engineer Mr. Dorning acted for the Earl of Derby, the Earl of Sefton, the Earl of Wilton and many other landowners in the north. He was standing arbitrator for the Corporation of Manchester, for which body he purchased 25 miles of land required for the Thirlmere conduit pipe. He was frequently engaged for other corporations in Lancashire and also as a witness in engineering and compensation cases involving large public and private interests. Mr. Dorning had been sitting for three days as arbiter in a case arising out of the purchase of land by the Liverpool, St. Helen's and South Lancashire Railway Company, when he was taken ill. He died at his residence, Pendlebury Cottage, Manchester, on the 18th of July, 1896, at the age of 77. Mr. Dorning was elected a Member on the 6th of December, 1864.

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FREDERIC GEORGE FISHENDEN, born on the 31st of July, 1832, was the son of Mr. William Fishenden, of Sheerness. At the age of seventeen he became a pupil in the Engineering Department of Sheerness Dockyard, where he remained for two years. He then obtained further practical training in the shops of Mr. Hall, contractor for fortification works on the Medway, after which he was engaged for three years as Assistant to Mr. J. Harrison in carrying out drainage and other works in that district for the War Department.

In 1857 Mr. Fishenden entered the Director of Works Department of the Admiralty, in which he served for nearly forty years. He was at once sent to Bermuda, where he remained for five years as Foreman of Works during the reconstruction of the dockyard and other naval establishments. From 1862 to 1871 he was employed, under Mr. Richard Townshend,[1] on the heavy and costly work of extending Keyham Dockyard. In 1872 he was appointed Clerk of Works on the Chatham Dockyard extension, and between that date and 1879 he carried out, under Admiralty orders, extensive works in connection with the reconstruction of the Cape of Good Hope Naval Establishments. On returning to England he was appointed Assistant Civil Engineer in charge of the harbour and breakwater at Portland, including the extensive Government quarries in the island and the supervision of the Admiralty Works in the district.

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 492.

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In 1883, again under Admiralty instructions, Mr. Fishenden proceeded to New South Wales, to make arrangements and prepare designs for the establishments required in that colony for the use of the Imperial Navy. He returned to Portland in the following year and in 1887 was appointed Superintending Civil Engineer of the Western District, in which are included the Dockyards at Devonport and Keyham and the charge of Plymouth Breakwater. There he remained until 1890, when he was transferred to Chatham Dockyard in a similar capacity. The duties of the Superintending Engineer of a large dockyard, in which the construction of warships is being carried on, are of an onerous nature, and were performed by Mr. Fishenden with the ability and zeal he brought to bear upon everything he took in hand. One of his last actions at Chatham was to assist in receiving a large party of Students of the Institution who visited the dockyard on the 9th of May, 1895. Early in the following year he was transferred to his old station at Devonport, where he died on the 10th of April, 1896. Mr. Fishenden was elected a Member on the 5th of February, 1889.

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JOHN WILLIAM GRAY, born on the 1st of October, 1828, at Montrose, was the son of Mr. Thomas Gray, general merchant and shipowner. As a boy he showed aptitude for mechanics, spending hours in working at the lathe and in making himself acquainted with the machinery in a flax mill, near Montrose, belonging to his father. At fifteen he was apprenticed to Mr. John Murray,[1] then Engineer to the River Wear Commissioners. During the next four years he was employed, at first under Mr. Murray and subsequently under Mr. Thomas Meik,[2] on Sunderland Harbour works and on marine surveys for the South Docks at that port. He was next engaged, from 1847 to 1852, in assisting Mr. W. C. Mylne[3] to carry out extensive works for the New River Company, after which he spent five years in the service of the East London Waterworks Company, under Mr. Charles Greaves.[4] In 1858 he returned to Mr. Mylne and for the next three years was occupied in re-arranging the system of supply in the New River Company's district. From 1861 to 1864 he was again employed by the East London Company, after which he set up in business on his own account. Among his first works were

[1] Minutes of Proceedings Inst. C.E., vol. lxxi. p. 400.
[2] *Ibid*, vol. cxxv. p. 410.
[3] *Ibid*, vol. xxx. p. 448.
[4] *Ibid*, vol. lxxvi. p. 355.

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the erection of rifle butts at Wimbledon and the preparation of a report on some proposed harbour works at Holywell on the Dee. He then spent some months in Russia reporting upon schemes for the water-supply and tramway system of Odessa.

On his return to England Mr. Gray was appointed Engineer to the Birmingham Waterworks Company. At that time—January, 1866—the Company was unable to provide an adequate supply of water and Mr. Gray at once advised various extensions, which were duly carried out under his direction. The pumping power at Aston was increased and a deep well was sunk there, water being also obtained from other new wells. In 1876 the works of the Company were purchased by the Corporation of Birmingham, Mr. Gray being retained as Engineer. He then sank a deep well at Selly Oak, and constructed a large storage reservoir at Shustoke, besides improving and enlarging the works at Plant's Brook, Aston, King's Vale and Longbridge, and also advised and carried out the installation of hydraulic power now at work. But the rapid increase of population rendered these measures inadequate, and the question of further sources of supply became one of grave moment. He then advised the Water Committee to seek for fresh sources of supply and recommended that they should take into consideration a modification of the scheme proposed by Mr. (now Sir Robert) Rawlinson in 1871, viz., to bring water from the gathering grounds of the Elan and Claerwen, tributaries of the Wye, in Mid-Wales. Mr. Mansergh, who was called in, confirmed Mr. Gray's recommendation. It was intended that, while Mr. Mansergh should be responsible for the works in Wales and for the construction of the conduit to Hagley, Mr. Gray should have charge of the section between Hagley and Birmingham. Unfortunately, however, his health failed, and in July, 1894, Mr. Gray retired, the City Council granting him a pension of £600 per annum on the understanding that his services should still be available in a consultative capacity.

Mr. Gray did not long enjoy his well-earned leisure. His health gradually became worse and for the last year he was practically confined to his bed. He died at his residence in Leamington on the 14th of August, 1896. He was a man of a large heart and generous nature, always ready to assist anyone in distress, and a kind and genial chief. He was a keen sportsman, never more happy than when thrashing a stream or tramping the moors with dog and gun. He was also a horticulturist of no mean ability. Mr. Gray was elected a Member on the 7th of May, 1872.

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WILLIAM HASKINS, born on the 27th of May, 1828, at Coolkenno Hall, co. Wicklow, was the son of the late Mr. Abraham Haskins. After being educated at Dublin, he served three years under Mr. Furlong, engineer and surveyor to Earl Fitzwilliam. Emigrating in 1852, he obtained a post as an Assistant Engineer on the Great Western Railway of Canada, on the survey and construction of which he was engaged for two years.

In October, 1856, Mr. Haskins was appointed City Engineer of Hamilton, Ontario, which position he held until his death. When the city took over the waterworks from the Board of Commissioners in 1861, the duties of manager were entrusted to him in addition to those he already performed. He made himself conversant with every detail of the Waterworks Department and brought it to a high state of efficiency. Shortly before his death he prepared a number of plans, minutely describing the whole system, and also designs for sewage disposal works at the outlets of the Wentworth Street and Ferguson Avenue sewers.

Mr. Haskins died at his residence in Hamilton on the 5th of July, 1896. He had attended at his office up to the previous day, although for the past two years he had not enjoyed good health. Death was due to a stroke of apoplexy, from the effects of which he never regained consciousness. Mr. Haskins was a Member of the Canadian Society of Engineers and was qualified to practise in the Dominion as a land surveyor. He was elected a Member of the Institution on the 7th of April, 1891.

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JOHN MUIRHEAD, eldest son of the late Mr. John Muirhead, of Upper Norwood, was born at Salton in Haddingtonshire on the 11th of March, 1846. After being educated at University College, London, he was appointed, at the age of twenty-one, manager to Messrs. Warden and Company, with which firm he remained until 1876. During that time he was principally occupied in the preparation of telegraph plant and in the erection of telegraph lines in all parts of the world, including about 700 miles in the Cape of Good Hope. In 1877 he entered into partnership with Mr. Latimer Clark, with whom he carried on business as an electrical engineer.

Mr. Muirhead will, however, be best remembered as the introducer—in conjunction with his brother, Dr. Alexander Muirhead —of the system of duplex working through submarine cables, which

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practically doubles the number of messages passing through the wire in a given time. This system, which is now in general use by the various cable companies, was first adopted by the late Sir John Pender on the Anglo-Indian cables, where it was worked in conjunction with Lord Kelvin's siphon recorder.

Mr. Muirhead died, from Bright's disease, at his residence, 20 Lower Belgrave Street, S.W., on the 21st of November, 1895. He was a man of great energy and business capacity, and his death at the age of fifty, after only a few weeks' illness, was a severe shock to his many friends. Mr. Muirhead was elected a Member on the 27th of May, 1884.

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EDWARD NEVILL BANKS, born on the 7th of May, 1845, was the son of Mr. Benjamin Banks, of Dublin. At the age of sixteen he was articled to Mr. B. T. Patterson, engineer and surveyor, of Dublin, with whom he remained as an assistant until July, 1866. In the following March he began to practise on his own account in Belfast, where he continued for the remainder of his life. Among the works upon which he was engaged were the sewerage and water-supply of Bangor, co. Down; the Stoneyford extension of the Belfast Waterworks, under Mr. L. L. Macassey; and the Ballymena Water-supply and Sewerage Works, under Mr. John Lanyon. He also frequently acted as arbitrator and as a witness in disputes connected with land drainage and injury by floods.

Mr. Banks died at his residence, Malone Road, Belfast, on the 17th of April, 1896, after a short illness, the cause of death being the rupture of a blood-vessel. In addition to his professional duties he took a useful part in civil and philanthropic life. He was for some time a member of the Corporation of Belfast, and worked with enthusiasm and self-denial on behalf of the Church Missionary Society and the Protestant Orphan Society. Mr. Banks was elected an Associate Member on the 13th of January, 1891.

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EDWARD HUGH DAY, the fifth son of Mr. Gerard James Day, of Horsford, near Norwich, was born on the 30th of July, 1868. He commenced his engineering career in 1886 as an apprentice in the works of Messrs. Aveling and Porter at Rochester, where he remained two years. He then served a short apprenticeship to Mr. William Marriott, Engineer and Locomotive Superintendent

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of the Eastern and Midlands Railway. From July, 1890, to December, 1892, he was Resident Engineer for Messrs. Thomas Meik and Sons on the Forfar and Brechin Railway, after which he returned to Mr. Marriott as Clerk of the Works on the reconstruction of Potter Higham Bridge, on the Eastern and Midlands line. He then acted as Resident Engineer for Mr. R. M. Parkinson on the Lostwithiel and Fowey extension of the Cornwall Minerals Railway.

In 1895 Mr. Day was appointed an Assistant Engineer on the Bengal-Nagpur Railway. Unfortunately his health, which had never been very robust, was unable to stand the Indian climate, and an attack of cholera ended fatally in twelve hours. He died at Bannapur on the 31st of March, 1896. Mr. Day was most conscientious and painstaking in all he undertook and his genial disposition made him a general favourite. He was elected an Associate Member on the 22nd of May, 1894.

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JOHN FENWICK, born at Newcastle-on-Tyne on the 4th July, 1826, was the second son of Mr. Simon Fenwick, for many years in the service of the London, Brighton and South Coast Railway Company. So long ago as 1840–41 he was engaged in the locomotive department of the Croydon Railway. He then served an apprenticeship of seven years, first with Messrs. Gordon, millwrights and engineers, of Deptford, and afterwards with Messrs. Sharp Brothers, of Manchester. From 1849 to 1851 he was in the employment of Messrs. W. Fairbairn & Co., and in 1852 he was in the locomotive department of the London and South Western Railway. Mr. Fenwick was next for two years engaged for Messrs. Rigby, the contractors, in charge of the plant for Holyhead Harbour works. From 1853 to 1855 he was foreman boiler-maker at the Wolverton shops of the London and North Western Railway, after which he was for three years foreman of the fitting shop at Messrs. J. and G. Rennie's marine-engine works.

In 1858 Mr. Fenwick proceeded to Western Australia as Resident Engineer for the Geraldine Mining Company. There he was engaged for two years in developing copper and lead mines. He returned to England in 1860 and was employed for five years in superintending for Messrs. J. and G. Rennie the erection of the iron floating dock at Cartagena, Spain.[1] He was

[1] Minutes of Proceedings Inst. C.E., vol. xxxi. p. 309.



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next manager for Messrs. Walpole, Webb and Bewley, shipbuilders, of Dublin, until 1870, when he set up in business in that city as a mechanical engineer. In 1874 and 1875 he was engaged at the Royal Marine Arsenal at Lisbon, and from 1876 to 1878 he was employed at the Barrow New Docks, Barrow-in-Furness. In the following year he was appointed manager to the Victoria Graving Dock Company, of London, which post he held until 1883.

From that time Mr. Fenwick, with the exception of some work in connection with the repairing of the gates of the Barrow New Docks in 1890, was not actively engaged. His last years were spent at Burnham, Somerset, where he died on the 20th of April, 1896. Mr. Fenwick's career, extending over fifty years, was of a very varied character, embracing as it did locomotive and marine-engine work, mining, shipbuilding and dock-work. He was elected an Associate on the 9th of January, 1872, and was subsequently placed in the class of Associate Member.

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EDWARD BERESFORD HEARNE, M.E., only son of the late Rev. Frederick Hearne, M.A., Rector of Groomsport, co. Down, was born at Malin, co. Donegal, on the 13th of October, 1854. He was educated at Trinity College, Dublin, where he graduated in Arts and Engineering in 1876. In 1888 he took the degree of Master of Engineering. After serving an apprenticeship to Mr. James Price,[1] Chief Engineer of the Midland Great Western Railway of Ireland, he was engaged on parliamentary and other surveys. In 1880 he acted as an Assistant Engineer, under the Board of Public Works of Ireland, on relief works in co. Galway, after which he was for five months contractors' engineer on the Limavady and Dungiven Railway. Mr. Hearne's next post was that of Assistant to the Borough Surveyor of Newry for four years, during which period he acted as Resident Engineer on the Armagh Waterworks, the Dungannon Sewerage Works and district sewers in Newry, and assisted in the construction of the Bessbrook and Newry Electric Tramway.[2] From March, 1885, to January, 1888, he was again in the service of the Board of Public Works as Resident Engineer on Carlingford Pier and Harbour, co. Louth, and on Annalong Harbour, co. Down.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxi. p. 327.
[2] *Ibid*, vol. xci. p. 193.

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Early in 1888 Mr. Hearne was engaged under Mr. J. C. Bretland in designing various sections of the Belfast Main Drainage, and in August of that year he was appointed Resident Engineer on those works upon which he remained until their completion at the end of 1895, when his engagement with the Corporation terminated. Mr. Hearne's promising career was prematurely cut short by the rupture of a blood-vessel on the brain, which caused death, after a few hours' illness, on the 23rd of April, 1896. He had endeared himself to all who worked with him by his kind and courteous manner and his unselfish character. He was elected an Associate Member on the 7th of April, 1891.

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HERBERT HINDS, born on the 10th of December, 1864, was the son of the late Mr. George Hinds, of Goudhurst, Kent, solicitor, and one of the coroners for that county. After being educated at Queen Elizabeth's Grammar School, Cranbrook, and at King's College, London, of which he became an Associate, he was articled in 1885 to Mr. Edward Easton for three years. In November, 1888, he was appointed assistant to Mr. Edward Robins, Colonial Engineer in Dominica, Leeward Islands. There he remained fifteen months, setting out roads and superintending the landing and erection of iron bridges. In the spring of 1890 he returned to England and entered the office of Mr. Edward Easton as an assistant.

In the following August Mr. Hinds sailed for New York, where he was engaged for three years on the construction of the Hudson River Tunnel for Messrs. S. Pearson and Son, the contractors. During the last two years he was in charge of the works. In the summer of 1894 he left the service of Messrs. Pearson and Son and proceeded to Johannesburg, where he practised on his own account until the recent disturbances in the Transvaal. He then went to the Orange Free State, and it was on business connected with gold mines there that he was returning to England, when he was drowned in the wreck of the "Drummond Castle" off Ushant on the night of the 16th of June, 1896. Mr. Hinds was elected an Associate Member on the 20th of May, 1890.

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HERBERT EDGELL HUNT, born on the 25th of November, 1847, was the son of Mr. George Lewis Hunt, of Westminster. After passing through the Applied Sciences Department of King's College, London, he was from 1866 to 1870 with Mr. James B. Walton, under whom he made surveys for the Ashby and Nuneaton Railway, the Romiley, Stockport and Manchester Railway, and several smaller lines for the London and North Western and Midland Companies. He then served for two years under Mr. William Clarke on the Whitchurch and Tattenhall Railway in Shropshire and on the Bristol and North Somerset Railway.

In May, 1872, Mr. Hunt was appointed a District Engineer, under Mr. William Lloyd, on the exploration surveys of a line across the empire of Brazil from the Atlantic Ocean to the borders of Bolivia, called the Paraná and Matto Grosso Railway. He carried out about 170 miles of railway surveys and 400 miles of river surveys through dense primeval forests, a work of great hardship and privation, besides the risk to health involved in sleeping for two years under canvas in a tropical climate. He also rendered great service in the final arrangement of the plans for the Brazilian Government. The Paraná and Matto Grosso line not being carried out, Mr. Hunt devoted himself to the further development of the railway system in Brazil. He was entrusted by Dr. Magalhaes, the concessionaire of the Minas and Rio Railway, with the surveys and final location of that line. Shortly afterwards, in 1880, this railway fell into the hands of Messrs. Waring Brothers, through Mr. Hunt. In conjunction with that firm he formed the present Minas and Rio Railway Company, raised the capital for the construction of the works, carried them out and finally opened the line for public traffic on the 14th of June, 1884. While conducting those works, Mr. Hunt —for himself and Messrs. Waring—undertook for the Government of Brazil the opening up of a portion of the Province of Espirito Santo, by surveying a very rough country from the Port of Victoria to Natividade, both in that Province, for the purpose of railway construction.

After the completion of the Minas and Rio Railway, Mr. Hunt returned to England and took no further active part in the profession. He died on the 7th of March, 1896, at Monte Carlo, within a few days of the death of his friend, Mr. Douglas Austhwaite Stanley,[1] in tending whom he was himself attacked by

[1] Minutes of Proceedings Inst. C.E., vol. cxxv. p. 414.

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fatal illness. The two inseparable friends lie in rock-hewn tombs side by side in the cemetery of Monte Carlo. Mr. Hunt was elected an Associate on the 2nd of March, 1875, and was subsequently placed in the class of Associate Member.

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NORMAN WILLIAM ROY, son of the late Mr. William Roy, of New Orleans, U.S.A., was born in Dundee on the 1st of October, 1862. From 1878 to 1883 he served articles to Messrs. Thomas Meik [1] and Son, and during that time he attended classes at the Watt Institution, Edinburgh, where he obtained several certificates and prizes. He next acted an an Assistant on the River Witham Outfall Works [2] and in 1885 returned to Edinburgh and attended the University classes there for some time. In 1886–87 he was employed on the works of the Thirlmere Aqueduct,[3] for the contractors, and on Warkworth Harbour, Northumberland, for Messrs. Meik and Son.

On the 1st of September, 1887, Mr. Roy sailed for India, having been engaged by Messrs. Glover & Co. for the contractors' staff for the Saugor branch of the Indian Midland Railway. As agent in charge of at first 17 and afterwards 24 miles of that line, he displayed, during the twenty months occupied by the construction, untiring energy, ready resource in all difficulties and great tact in the management of the numerous petty contractors by whom the work, with the exception of plate-laying and the erection of girders, was carried out. It may be mentioned that during the first season of working there were over 30,000 men, women and children employed on the 46 miles of the Saugor branch. Mr. Roy, fresh from home and with only native assistants, had to deal with at least half of this great labour force. So judicious was his management that no disturbance of any kind occurred, and so well were the sanitary arrangements carried out by him and his fellow agents that there was hardly any sickness, other than fever, all along the line.

On the completion of the Saugor contract in July, 1889, Mr. Roy joined the staff of Mr. G. Murray Campbell, for whom he set out the Rawang extension (20 miles) of the Selangor Government Railways, and acted as Chief Agent until the opening of that section of the line. There, as in India, his capacity for organizing

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[1] Minutes of Proceedings Inst. C.E., vol. cxxv. p. 410.
[2] *Ibid*, vol. xcv. p. 78. [3] *Ante*, p. 2.

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and controlling native labour was of great value. Next, until February, 1894, Mr. Roy was in charge of 20 miles of line to Kuala Kubu for the Government. He then joined Mr. Campbell in Siam and took charge of a section of the Korat Railway, the work on which was the heaviest on the whole line. Half the labourers had died from fever and the rest had fled, but the difficulties Mr. Roy had to face only brought into greater prominence his powers of organization. In three months the district was fully manned, a water-supply arranged and shops established for the sale of provisions. But the climate and exposure had begun to tell even on his iron frame, the more so that he would take no rest. A chill, followed by malarial fever and other complications, necessitated his removal to the Bangkok Hospital, where he died on the 16th of May, 1896, full of courage to the last.

Mr. Roy was elected an Associate Member on the 4th of December, 1888.

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LUKE GEORGE SGOUTA, born in 1854, was educated at the High School of Halki, one of the Princes Islands in the Sea of Marmora, which he left in 1870 for Geneva, where he studied engineering for five years. He came to England in 1875 and served a pupilage of twelve months to Mr. Joseph Kincaid, under whom he made surveys and prepared plans for tramways at Bristol, Gloucester and Leeds. He was next apprenticed for two years to Mr. John Fraser,[1] of Leeds, for whom he acted as a Resident Engineer on the Batley and Dewsbury Railway.

In July, 1878, Mr. Sgouta proceeded to Constantinople and two years later was appointed Second Engineer on the Scutari and Ismid Railway in Asia Minor. In 1882 he established himself in Greece and during the next fourteen years took an active part in several important enterprises in that country, among which may be mentioned the drainage of Lake Copaïs and the construction of the harbour of Catacolo. He was also connected with various Greek mines, and he prepared plans for the port of Heraclea on the Black Sea. Mr. Sgouta died at Athens on the 17th of February, 1896, from pneumonia. He was elected an Associate Member on the 7th of December, 1880.

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 417.

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NORMAN MAUGHAN TAYLOR, the youngest son of Mr. G. Noble Taylor, Chairman of the Madras Railway Company, was born at Simla on the 17th July, 1868, and was educated privately in England and in Germany. In 1888, after two years' training at the Crystal Palace School of Engineering and at the City and Guilds of London Institute, he was for a few months on the Great Southern of Spain Railway. He was then for about a year under Mr. Harold Abernethy[1] on the Runcorn section of the Manchester Ship Canal. In October, 1889, he was sent by Mr. James Livesey to Mexico, where he acted as an Assistant Engineer under Mr. Henry Parkes on the Mexican Southern Railway until its completion in 1893, when he returned to England. In the autumn of the same year he went to India and was employed on the survey of the Bombay, Baroda and Central India Railway Company's projected line from Rutlam to Agra.

In September, 1895, Mr. Taylor was attacked by pleuro-pneumonia. A long and painful illness followed which he bore with courage and patience. He was brought home from India in the following April in a deplorably weak state and on the 22nd of May, 1896, he died at his father's house in London. He was regarded by those under whom he served as a promising young engineer and his memory is warmly cherished by all who knew him. Mr. Taylor was elected an Associate Member on the 4th of December, 1894.

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FREDERICK HOWARD WATSON, B.A., born on the 24th of July, 1863, obtained a Foundation Scholarship at Trinity College, Cambridge, where he graduated 26th Wrangler in the mathematical tripos of June, 1884. He then attended for two years the lectures of Professor Stuart at the University Engineering Workshops, where he also gained some practical experience. During 1886–87 he studied in the Engineering Laboratory at University College, London, under Dr. Kennedy, and in August of the latter year he was engaged by Messrs. Tancred, Arrol & Co. on the construction of the Forth Bridge. He assisted in the calculations for the temporary staging and appliances for its erection until October, 1888, when illness compelled him to give up work. Mr. Watson died on the 9th of October, 1895. He was of a quiet and studious disposition and a great lover of music. He was elected an Associate Member on the 3rd of December, 1889.

[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 363.

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WILLIAM HERBERT WHEELER, B.A., elder son of Mr. William Henry Wheeler, Harbour Engineer of Boston, was drowned, with his brother Ralf, off Skegness on the 28th of June, 1896. The brothers were sailing to Hull in their yacht, a vessel of about 4 tons, and having moored her for the night off Skegness were returning from shore when the skiff in which they were rowing was carried out of its course by a strong southerly current. In their endeavour to make fast to a buoy, towards which the current had carried them, the skiff was capsized and its occupants were drowned.

The subject of this notice was born on the 11th of May, 1867, and was educated at Cheltenham College and at Cambridge University, where he attended the engineering course and graduated with honours. In June, 1887, he was articled to his father, with whom he subsequently remained as an assistant. In that capacity he made surveys for the canal to join the Aire and Calder Navigation with the South Yorkshire Canal, and for the Shipcote Drainage, the works of which he afterwards superintended under his father's direction. He also made surveys and observations for reports on the improvement of the River Wharfe and of the River Colne from Colchester to the sea; and took tidal and other observations of the Ribble and the Parrett for a similar object. He successfully directed the raising and removal of the s.s. "Ethel," which had been wrecked in the Witham and was seriously impeding navigation; and he designed a new form of dredger called the "Eroder" dredger, by means of which shoals in the Witham were removed at a very small cost. He assisted in reorganizing the lighting of Boston Deeps and the River Witham by an improved system of leading lights, by which the approach from the sea was much facilitated, and at the time of his death he was employed in superintending the dredging and deepening of the river from Boston Deeps to the sea.

Mr. Wheeler was elected an Associate Member on the 6th of December, 1892. As a Student he had previously read a Paper on "The Cleaning and Deepening of Rivers and Canals by means of the Transporting Power of Water," for which he was awarded a Miller Prize.

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HOWARD JOHN KENNARD, born in London on the 29th of November, 1829, was the son of the late Mr. R. W. Kennard, M.P. for Newport, Isle of Wight, and grandson of Mr. John

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Kennard, of Lombard Street, banker, whose business has developed into the Consolidated Bank. At an early age Mr. Howard Kennard became identified with the iron trade, with which his father had been connected for a long period. He joined the Board of the Falkirk Iron Company, in the management of which he took an active part for many years. During the Crimean War the Falkirk Ironworks were busy day and night turning out shells for the Government, and Mr. Howard Kennard spared neither time nor labour in keeping the output up to the mark required.

He was also Chairman of the Blaenavon Iron Company and a Director of the Great Eastern Railway Company. He was elected to the joint chairmanship, with Mr. J. T. Smith of Barrow, of the Rail Makers' Association, a combination of the leading iron and steel manufacturers of Great Britain formed for the purpose of regulating the rail trade. On the dissolution of that body he received an embossed shield as a mark of the esteem of his colleagues. In 1891 he was elected President of the Royal Metal Trades' Pension Society, which had been founded by his father in 1843. During the greater part of its existence he had taken much interest in the welfare of that body and on the occasion of its jubilee in 1893 he was most active in enlarging and extending the usefulness of the Society. So energetically did he go about to obtain subscriptions that he was called "The Beggar-General of the Trade," a designation which he by no means disliked.

Mr. Howard Kennard died at the Orleans Club, Brighton, after a short illness, on the 8th of August, 1896. In addition to his business in the iron world, he was connected with the London Stereoscopic Company, which he and his cousin, the late Mr. Alderman Nottage, jointly established. He was a Past Master of the Carpenters' Company, a Justice of the Peace for Stirlingshire and one of Her Majesty's Lieutenants of the City of London. As an employer of labour he was extremely popular. He could never bring himself to believe that his responsibility to his workmen ended with the payment of wages. He felt that the moral, social and intellectual interests of the people gathered together by the establishment of large undertakings, such as the Falkirk and the Blaenavon Ironworks, should not be ignored by their employers, and he lent willing aid to every institution promoted for the welfare of the workmen and their families. Mr. Howard Kennard was elected an Associate on the 13th of January, 1857.

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SIR JOSEPH PRESTWICH, M.A., F.R.S., full of years and of honours, passed into rest on the 23rd of June, 1896, after a life of unceasing activity in many widely different spheres. In his grave, in the little secluded village of Shoreham, in Kent, lies the last of the band of men who made geology a science—Buckland, Murchison, Sedgwick, Lyell, Phillips and De la Beche—and did their work so well that there is little left for the present generation but to fill in the details. Born on the 12th of March, 1812, at Clapham, and educated partly in London and partly in Paris, Joseph Prestwich received his first scientific impulse from the lectures of Dr. Turner and of Dr. Lardner at University College, Gower Street, where he gave special attention to chemistry and natural philosophy, including geology and mineralogy. When a mere boy he came under the influence of the founders of the Geological Society, which he joined in 1833, at the age of twenty-one. He contributed to the Transactions and Journal Papers on various geological questions, from early in the thirties to the closing decade of the century. These Papers, and more particularly the earlier ones relating to the classification of the Tertiary strata of Britain and France, give him a place in the annals of geology by the side of Sedgwick, Buckland and Murchison. What they did for the Primary he has done for the Tertiary Rocks, although until he was sixty years old he was in business as a wine-merchant and was unable to give his whole time to scientific work. In one respect his business furthered the study of geology by taking him over the greater portion of eastern and southern England and a large part of France. In his journeys he acquired the minute topographical knowledge which characterised his geological writings. His holidays were devoted to various special lines of inquiry. The memoir which he wrote for the Geological Society in 1836 on the geology of Coalbrookdale was the fruit of two years' holiday. It at once placed him in the high position which he held in British science to the end. Of his many contributions to geology it is not possible here to write in detail, but there is one which ought not to be passed over—his share in establishing the antiquity of man upon its present scientific basis. In 1847 Boucher de Perthes had announced the discovery that man was living in the valley of the Somme at the same time as the mammoth and rhinoceros, and that the fauna belonged to the period now known as Pleistocene. In Britain similar discoveries had been made by the Rev. J. MacEnery in Kent's Cavern, near Torquay, in 1825–30, and these were verified by Godwin-Austen in 1840

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and six years afterwards by the Torquay Natural History Society. They were, however, received with incredulity by the scientific world, both of France and England, until the exploration of Brixham Cave in 1858, carried out by a Committee of the Royal and Geological Societies, of which Prestwich was one of the prominent members. In conjunction with Mr. John (now Sir John) Evans he examined the evidence offered by the valley gravels of the Somme and of South-Eastern England, with the result that the contemporaneous existence of man with the mammoth and other Pleistocene mammalia was fully established by the year 1860, and the antiquity of man became one of the most interesting questions of the day. In his later years Prestwich held that the antiquity was small, rather than great, and brought it down to within an appreciable distance of the frontier of history —a conclusion not generally accepted by his scientific fellow-workers.

While Prestwich devoted his main energies to the study of geology, he was led gradually, by the close connection which exists between that science and civil engineering, to inquiries of great practical utility in dealing with two of the most important questions of the day—coal and water-supply. He had mapped the coalfield of Coalbrookdale early in the thirties, and he followed up this research in later years by the study of Northern France and Southern England, along with Godwin-Austen. When, therefore, the latter published his views as to the range of the coalfields in Britain, from Somerset eastwards into Northern France, Prestwich fully accepted them. He was appointed a Member of the Royal Commission on Coalfields in 1866 and drew up two reports; one on "The Quantity of Unwrought Coal in the Coalfields of Somerset," and another on "The Probability of Finding Coal under the Newer Formation of the South of England." Godwin-Austen gave evidence and Prestwich confirmed it, taking the favourable view in opposition to his fellow-commissioner, Murchison, who considered that there were no coalfields in South-Eastern England. The Report of the Commission has led to a large development of the mining industry in the areas where the coalfields are concealed by the newer rocks, in the Midland Counties, in South Yorkshire and in Nottinghamshire. It caused an experimental boring to be carried down to a depth of 1,905 feet at Netherfield, near Battle, by Henry Willett and a committee, which proved the absence of Coal Measures to a depth of some 2,000 feet below the surface. It led to the selection of Dover by Boyd Dawkins for a further experiment, which, under the guidance of Sir Edward

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Watkin, has proved the existence of the South-Eastern Coalfield, that may sooner or later turn the Weald of Kent into a great manufacturing centre.

The question of the water-supply to the metropolis has been to the fore from the third decade of this century and is still pending. In 1851 Prestwich contributed to it a work on the Water-bearing strata round London, which is the first systematic book on water-supply and up to the present time without a rival.[1] In it he has diligently collected the scattered observations of Robert Stephenson, Homersham and others, and combined them with his own researches and experiments. The principles which he lays down have not been modified by the discoveries of the last half century, although some of the details, such as the range of the Lower Greensand under London, now known to be absent, have been modified by later borings. In 1867 he took a prominent part in the work of the Commission on the Metropolitan Water-Supply presided over by the Duke of Bedford.

In 1872 Prestwich retired from business and two years later he was appointed Professor of Geology at Oxford, which post he held until his resignation in 1888. While occupying that chair he published a work on geology in two volumes—notable as containing the best description of underground water, springs, &c., to be found in any book on geology—and these researches were continued on his retirement.

In recognition of the value of his work, in 1849 the Geological Society gave him the Wollaston Medal and in 1865 the Royal Society awarded him the Royal Medal. In 1885 he was elected a Corresponding Member of the Academy of Sciences in Paris and in 1896 he received the honour of Knighthood. He closed his life surrounded by the warm affection of all who knew him, and has left behind a name which will live in the scientific annals of this century.

Prestwich was elected an Associate of the Institution on the 7th of December, 1869, his proposition paper setting forth that "by his scientific acquirements as a geologist he is qualified to concur with Civil Engineers in the advancement of professional knowledge." In 1873 he contributed a Paper "On the Geological Conditions affecting the Construction of a Tunnel between England and France,"[2] for which he was awarded a Telford Medal and Premium,

[1] This work is in the Library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 110.

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and two years later a second Paper, "On the Origin of the Chesil Bank, and on the Relation of the existing Beaches to past Geological Changes independent of the present Coast Action,"[1] for which he obtained a Telford Premium.

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MAJOR-GENERAL JOHN SALUSBURY TREVOR, C.S.I., late R.E., who died on the 9th of June, 1896, at his residence, 75 Ladbroke Road, Notting Hill, was the son of Captain Robert Salusbury Trevor of the 3rd Bengal Cavalry. He was born at Cawnpore on the 30th August, 1830, and when ten years of age accompanied his parents to Cabul. In the disaster which overtook the British force under General Elphinstone in 1841–42, his father was killed, and he, with the other members of the family, was among the hostages made over to the Afghans in the course of negotiations to obtain terms. The hostages were rescued after General Pollock's re-occupation of Cabul in 1842 and accompanied his force on its return to India in the same year.

Young Trevor was a boy of twelve when he first came to England. Two years after he entered the Royal Military College at Addiscombe, where his strong mathematical ability obtained for him a commission in the Bombay Engineers in 1847. After the usual course of study at the School of Military Engineering at Chatham, Mr. Trevor proceeded to India and was employed as Assistant Superintendent of Roads and Tanks from 1849 to 1855, when he was transferred to the Railway Department as Deputy Consulting Engineer. In 1861 he was made a member of the Bombay Municipality, in addition to his other duties.

In 1864, owing to a severe attack of fever, Captain Trevor—he had been promoted in 1858—was compelled to take leave to England. On his return to India two years later, he was appointed Executive Engineer of the Tapti Irrigation Works. On the occurrence, however, of a vacancy in the Railway Department, he was transferred to that branch of the service, and in 1868 became Consulting Engineer and Under Secretary to the Government of Bombay. In the previous year he had been promoted Lieutenant-Colonel and in 1870 he was appointed Chief Engineer of the Presidency. During 1871 and 1872, in the latter of which years he was promoted Colonel, he acted as Deputy

[1] Minutes of Proceedings Inst. C.E., vol. xl. p. 61.

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Secretary to the Government of India in the Railway Branch, and was then again obliged by ill-health to take leave to England.

Colonel Trevor's health was not sufficiently restored to allow of his returning to India until June, 1878, when he was appointed Officiating Deputy-Secretary to the Government of India in the Railway Branch. At the end of that year he retired from the army with the rank of Major-General. His services as an administrative officer were, however, considered of such value by the Government of India that he was requested to retain his departmental appointments and on the creation, in 1880, of the post of Director General of Railways in India, he was selected to fill it. In addition to the duties of that office he also acted for some time as Secretary to the Government of India in the Public Works Department.

In March, 1881, General Trevor finally severed his connection with the service, receiving the Companionship of the Order of the Star of India in recognition of his work as a departmental officer. He then returned to England, where his wide experience and profound knowledge of the working of Indian Railways were utilized by several of the Guaranteed Companies, on the Boards of which he had a seat. At the time of his death he was Chairman of the Bombay, Baroda and Central India, the Southern Mahratta and the Rohilkund and Kumaon Railway Companies, all of which are greatly indebted for the prosperity of their several undertakings to his accurate knowledge of the local conditions affecting their working and to the untiring energy with which he devoted himself to the promotion of their interests. He was elected an Associate on the 4th of March, 1873.

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*** The following deaths have also been made known since the 10th of August, 1896:—

*Members.*

BIRCH, ROBERT WILLIAM PEREGRINE; *born* 25 Sept., 1845; *died* 30 August, 1896. (*Erysipelas.*)

SIMEON, LIONEL BARRINGTON; *born* 6 Nov., 1852; *died* 30 August, 1896. (*Atrophy of the digestive organs.*)

*Associate Members.*

LAWSON, JAMES IBBS; *born* 7 February, 1869; *died* 2 July, 1896.

NEWDIGATE, EDWARD; *born* 22 July, 1866; *died* 25 August, 1896. (*Typhoid fever.*)

SCHEID, HENRIQUE; *born* 12 December, 1829; *died* 20 March, 1896.

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., *September*, 1896.

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## Sect. III.

## ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

### *Auxiliary Telescope for Mine Theodolites.* By F. W. Denton.

(Engineering and Mining Journal, New York, vol. lxi., 1896, p. 183.)

The Author describes and illustrates a new form of auxiliary telescope for mine theodolites that is a decided improvement over the instrument in common use. The special feature is that the telescope is interchangeable, and may be used either as a side or top telescope; the eccentricity being the same in both positions and only one counterweight being necessary. The attachment of the auxiliary to the main telescope is effected by means of a single central pillar which is permanently fastened to the main telescope. If used at the side, the auxiliary telescope is screwed to the end of the horizontal axis. The relative merits of side and top auxiliary telescopes have long been subjects of discussion by mine surveyors, but experience tends to show that both forms are necessary in order to obtain the best results.

B. H B.

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### *Errors in the Use of the Gradienter.* By B. S. Lyman.

(Engineering News, New York, vol. xxxv., 1896, p. 370.)

The successful use of the micrometer in astronomical instruments has apparently created the impression that the same principle could be satisfactorily applied in the form of the gradienter. If, however, the details of construction of the gradienter are considered, it will be seen that there are several sources of error in its work, so much so that it has sometimes been found necessary to make two complete turns of the gradienter screw before the telescope moves at all. The chief source of inaccuracy is due to the fact that the gradienter screw is far more exposed to dust than an astronomical micrometer screw. Such screws are therefore very liable to wear and to give less uniformity in motion than delicate measurements require. The length of the screw is apt to cause it to become slightly bent, so that in different parts of each turn unequal effects would be produced on the motion of the telescope. Again, the gradienter screw does not merely move directly a light micrometer slide but a long lever, the clamp transmitting the movement ultimately to the telescope itself. When the screw is turned there is a slight yielding of the inter-

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mediate parts before the telescope moves. The truly practical application of the principle of the astronomical micrometer to surveying instruments is in the adjustable cross-wires for tacheometer reading, and such tacheometer work is more trustworthy for distance measuring and less laborious than the corresponding gradienter work.

B. H. B.

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*Seasoning-Plant for Drying Timber.* By RICHD. EIKENWEL.

(Gesundheits-Ingenieur, 1896, p. 155.)

After pointing out that the simplest plan of drying wood is to stack it in the open, in such a way that the air has free access to all parts—a process involving considerable time, viz., about one year for floated logs sawn into ordinary scantlings, and from five months to six months for green, fresh-felled timber—the Author discusses the various processes for the artificial seasoning of timber. He claims for artificial drying when properly carried out the following advantages: (1) That the structure of the wood remains unaltered; (2) the elasticity and the strength of the material is proportionately much increased; (3) freedom from shakes; (4) no possibility of warping; and (5) retention of the natural colour, especially in the case of valuable timber, such as mahogany, walnut, etc. The design of suitable drying apparatus has, the Author maintains, been hitherto for the most part misunderstood, the degree of heat applied being excessive, and the provisions for withdrawing the heated air being inadequate. After many experiments, it has been ascertained that the best results are produced with air at a temperature of 122° Fahrenheit, instead of from 158° to 176° Fahrenheit, as now generally employed. Details are given (by reference to a plan and section) of the so-called "ventilation drying system," wherein air, heated to the requisite temperature by passing it over steam or hot-water pipes, is conducted through stacks of timber and subsequently exhausted at the requisite speed by means of a fan or blower. In addition to the heated air, arrangements are made to close from time to time the air-inlets, and to pass free steam into the chamber. This is done regularly three times daily for a quarter of an hour at a time, and the repeated steaming is said to soften the sap, to expedite the drying process, and to increase greatly the relative elasticity of the seasoned wood. A few heating pipes are placed beneath the floor of the chamber so as to dry up the condensed steam and moisture. The following conditions are laid down as being essential in order to ensure success in the working:—

(1) All the boards to be dried at the same time should be of uniform thickness.

(2) The spaces between the boards must in all cases be equal; and,

(3) The heating chamber must either be completely filled up

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with timber to be dried, or, if not full, the vacant space at the top must be boarded up in the same way as the space between the floor and the top of the timber-truck, on which the boards are stacked.

A series of formulas follow, showing the mode in which to calculate the heating power needed, the volume of air to be employed, the heating surface of the hot-water pipes, and the power of the fan or exhaust. These rules are subsequently applied to a known weight of timber to be seasoned, and all the calculations are worked out in detail.

G. R. R.

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*Ceramic Stone obtained by the Devitrification of Glass.*

By — GARCHEY.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 1277.)

The Author utilizes old bottles and broken glass containing earthy matter in excess, for the production, by a devitrifying process, of a stone-like substance, capable of use for decorative and other purposes.

The material, reduced to powder, is placed in moulds and subjected to a moderate heat for about an hour until it is reduced to a pasty consistence. It is then removed to a hotter furnace for a few minutes to complete the devitrification, and finally moulded or pressed into the required forms.

G. J. B.

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*The Use of Coarse Gravel for Cofferdams.* By — CLAISE.

(Annales des Ponts et Chaussées, April, 1896, p. 539.)

This Paper describes cases in which the Author has used coarse gravel for the construction of temporary cofferdams with success. The method of construction is simple; the gravel is tipped in the required position, and allowed to take its natural slope on both sides, the width of the top of the bank thus formed being about 3 feet. To render the gravel watertight, the Author employed tan, which was spread over the pressure face of the dam, rendering it practically impervious in a very short time. Other materials than tan could of course be used for this purpose.

The Author further describes the causes of possible failure and the methods of dealing with them. Dams of this type were used for the reconstruction of the bridge of Villette, near Sedan, the reconstruction of the Glaires bridge, and the removal of masonry in the Mézières branch—all on the canalized Meuse. The maximum head of water in these cases was nearly 9 feet.

The Author considers that this type of dam is specially suitable where (i.) it is impossible to drive piles; (ii.) it is difficult to



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launch a caisson, and (iii.) rapidity of construction and removal are of special importance. The cost of construction of the dams on the Meuse the Author states to have been as follows:—Coarse gravel 3¾*d.* per cubic yard (this was used twice over, and afterwards employed for road metalling). Carriage of gravel by water, a distance of over 2 miles, and tipping in place, 11*d.* per cubic yard. The tan was obtained for nothing, but its cartage to the site of the works, nearly 2 miles, cost 1*s.* 2½*d.* per cubic yard. The removal of the dam by dredging cost 7¼*d.* per cubic yard; and various other expenses amounting to 3*s.* 7½*d.* per yard run of the dam.

The Author concludes with the following precautions to be taken in the construction of gravel dams:—

(1) The gravel must be quite free from earthy matter, and not too fine; on the inner side it should be of such size as will not be carried away by any currents which may be caused. If too coarse on the outer side, it is more difficult to render watertight, and in any case a layer of finer stuff should be spread over the face.

(2) If the material is light, the pressure must be increased slowly and as the work becomes watertight.

(3) The dam should be watched as the pressure on it is increased, and should any movement take place on the inside, the head of water must be immediately reduced, the inner face reinforced, and the watertight inner layer increased.

There are two small illustrations in the text, one showing a section of the dam, and the other the way in which failure takes place.

R. B. M.

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## *The Mirabeau Bridge, Paris.*[1] By CH. TALANSIER.

(Le Génie Civil, 9 May, 1896, p. 17.)

This is a detailed description of a new road-bridge over the Seine at Paris, forming a continuation of the Rue de la Convention. It is a cantilever arch, with articulations on the piers and at the centre of the main span, the ends of the cantilevers being anchored to the shore abutments.

The total length of the bridge is 569 feet, the centre span being 326 feet from centre to centre of the knuckles on the piers, and the cantilever side spans being each 121 feet 6 inches from centre of knuckle to end of cantilever. The roadway is carried on seven main ribs, the five inside ones being spaced 9 feet 10 inches centres, and the outer ones on each side 12 feet 2½ inches centres. The carriage-way is 39 feet 4 inches, and the foot-ways on each side 13 feet 1½ inch wide. Each main rib consists of a straight double upper member of a constant depth, each half being of a built-up T shape, and a curved lower member of varying depth

[1] A fully illustrated account of this bridge will be found in *Engineering*, June 12, 1896, *et seq.*

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of a U shape; the two members merging into one another at the ends of the rib, and connected together between the ends by verticals and diagonals. These verticals are spaced uniformly 6 feet $6\frac{3}{4}$ inches apart. The rise of the lower member of the rib from the knuckle on the pier to the centre articulation is 18 feet. The seven ribs are connected together at the top by plate cross girders at every vertical, carrying the roadway; and at the bottom by lattice girders at every other vertical, and further stiffened at the latter points by crossed diagonal bracings.

The roadway over the cantilever spans is carried by jack arches between the cross girders, these jack arches being filled over with concrete, burying the top members of the ribs, and on this concrete the wood paving is laid. Over the centre span the concrete under the paving is much thinner and carried on plates supported by longitudinal channels and joists, which rest on the cross girders. This difference is made so as to load the side spans more heavily than the centre in order to relieve the stresses on the centre articulation.

Provision is made at the kerbs of the roadway to allow of expansion of the wood paving, to avoid throwing undue stresses on the structure. The footways are carried clear of the cross girders on plates and tees, leaving a space below for the gas and water mains, &c.

The main ribs are entirely of rolled steel, and the decks carrying the roadway of rolled iron; the knuckles are of cast steel, and all the pins and keys of forged steel, while the ornamental handrail and decoration of the bridge are of cast iron. The total weight of the metal work is 2,744 tons, of which 2,077 tons is rolled steel, 385 tons rolled iron, 77 tons cast steel, 5 tons steel forgings, and 200 tons cast iron.

Mr. Talansier finally gives a description of the principle of this type of bridge, and points out its advantages. The article is illustrated by a double page sheet of details, two views of the bridge completed, one being taken during the official tests, four views during construction, and a few small illustrative cuts in the body of the Paper.

R. B. M.

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*The Improvement of the Mouth of the Rupel.* By C. Van Mierlo.

(Annales de l'Association des Ingénieurs de Gand, 1896, p. 69.)

The Rupel is the principal tributary of the estuary of the Schelde, and carries a very large amount of traffic, giving access as it does to Brussels, Malines, Louvain, and by the Charleroi canal to the entire central basin of Belgium. In consequence of insufficient depth, its navigation formerly gave rise to considerable difficulties, and, for some two or three years past, works have been in progress to deepen and widen the channel. The state of the river before the commencement of these operations is described by reference to a series of charts. The first accurate survey was that



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made by Lieut. Stessels in 1863. His chart indicated soundings of over 16 feet in the Rupel; but these depths are not continuous, and occur only in the bends. Where the currents of the Schelde and Rupel unite, there is, in the former river, a deep trough, with maximum soundings amounting to 37 feet. In the direction downstream this depression is terminated by a bank, over which there is only 19 feet of water; but under the right bank of the Schelde, near Moerkil, the soundings again exceed 33 feet. It would seem that similar conditions have existed for a long series of years. During the First Empire, the confluence of the two rivers near Fort Ste. Marguerite was spoken of as a good anchorage for frigates and warships, and it may be assumed that the depths at least equalled those indicated by Lieut. Stessels, which, indeed, reappear in all the charts down to 1891. But even in 1863 the navigation was defective; the right bank of the Rupel, opposite Fort Ste. Marguerite, was extremely sloping, and this gave rise to a narrowing of the channel, and caused eddies and cross-currents, the general character of which is indicated in a survey chart made in 1888. Some of these interruptions of the flow moreover created shoals in the Schelde, on which wrecks were not uncommon. To avoid these evils the various training-works now under consideration were undertaken, and completed in 1893, at which time a fresh survey was made. The nature of the changes effected in the mouth of the river are set forth in a progressive series of charts. In the first place an embankment was formed along the right bank of the Rupel with a flatter curve than before. At the same time the left bank was also raised, and the curvature was made parallel with the other bank, the summits in each case being carried up to a point a little above the line of extreme high tides, and the upper portions were faced with stone. The spur or projecting tongue of land included between the fork of the two rivers was extended by a wooden cross-boom. The general form of the confluence was thus made tangential.

The effect of these works, which were apparently designed to distribute the tide between each river in the same proportions as formerly, is discussed, and the Author shows, by reference to charts for the years 1893–95, that the scour of the ebb is more considerable than that due to the flow of the tide, and that it would be advisable to so rearrange the confluence of the two streams as to give an increased area of tide-way at the mouth of the Rupel. He states that the results so far obtained, though of benefit to the Rupel, are unfavourable to the Schelde; and he indicates what ought, in his opinion, to have been done in order to obtain the desired effect. He does not believe that the Rupel will carry a greater depth of water than from 12 feet to 13 feet, if a larger channel is considered imperative; and if more depth is needed, recourse must be had to dredges.

G. R. R.

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## *The Port of Montevideo.*

(Preliminary Report of Sub-Commission appointed by the Uruguayan Government.[1])

In compliance with a contract concluded with Messrs. Luther by the Government, on April 22, 1895, that firm presented on Dec. 5th of the same year a preliminary scheme, setting forth the works proposed to be executed in constructing the Port of Montevideo. A commission appointed for the purpose has studied the report and plans submitted on behalf of Messrs. Luther, and has decided to accept their scheme, subject to certain modifications which are set forth and explained in the present document, to which are also appended the plans of the works in question. A brief account is given of the conditions under which the port has to be constructed, and containing a description of the site on which it has to be located. The Bay of Montevideo, which is semicircular in form, has an extreme width of about 2½ miles, and has an entrance towards the south about 1 mile across, the approach being somewhat constricted by the rocky promontory on which the city is built. The bay is more or less open towards seven points of the compass, and it contains within it three or four granite ridges which attain to an elevation of from 7 feet to 10 feet above high-water mark. Owing to a bar which obstructs the entrance to the outer roads, the harbour can now only be entered by vessels having a less draught than 16·4 feet. With the exception of the above rocky outcrops and the sandy foreshore towards the north, the bottom of the bay is in all parts of a soft muddy nature, resembling that found in the estuaries of all great rivers. A similar bottom is found outside the bay for a considerable distance out to sea, giving rise to a vast expanse of shallow mud, on which extensive sandbanks are formed. Between these are two chief depressions, with sundry channels available for navigation. The entire estuary of the River Plate is subject to very special tidal conditions which are fully discussed. A consideration follows of the prevailing winds and of the influence of the same on the ebb and flow of the tide. The highest tide known has risen to 10 feet above datum (= level of lowest neap tides); the lowest recorded tide = 1 foot 6 inches below datum; ordinary high water = 3 feet 4 inches above datum. The currents, except those due to wind, are not of great importance, but heavy seas are caused by a slight amount of wind, in consequence of the lightness of the fresh water. Changes of wind and weather take place so rapidly that the transhipment of passengers and merchandise is difficult and often dangerous. An account is given of the movements in recent years of the sand and mud, and concerning the deposit of the alluvium in the vicinity of the port. The actual condition of the Port of Montevideo at the present time is such that vessels of large draught anchor in the outer roads and tranship

[1] The original is in the Library of the Inst. C.E.

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their passengers to small steam launches, the cargo being transferred to lighters which range in size from 10 to 200 tons. The anchorage in the inner roads, where the depth averages from 10 feet to 14 feet 9 inches, is exposed to winds and heavy seas from the south. Vessels of larger size have to anchor in an unprotected position outside the bay, at a distance of from 2 to 2½ miles from the Point St. José, the bottom here being a soft mud, on which at times they stand exposed to the risk of stranding. The terms of landing are stated, and it would appear that the total cost per ton of cargo reaches 12*s.* if the ship is in the outer roads, or 7*s.* 6*d.* if the vessel is moored in the harbour. By comparison of these charges with those at Marseilles and Barcelona, it is shown that immense financial advantages would result from the construction of the port. A list of the present port dues on merchandise follows.

The preliminary project presented by Messrs. Arnold and Waldorp, on behalf of Messrs. Luther, comprises a large dock heading from the northern shore of the city, leading to an extensive outer harbour formed by two breakwaters, each about 2,180 yards in length, constructed in the exterior of the bay. The breakwaters are rectilinear in plan; the one on the west extends from the highest point of the Piedras Blancas rocks, more or less in a south-east direction, the other, leaving the shore near Sarandi Point, runs almost due south-west. They therefore converge towards each other until they reach the natural depth of water of 19½ feet, where their extremities are 383 yards apart, and between them flows the access channel to the port. The space to the north of these breakwaters has a total area of about 618 acres, all of which would require to be dredged to a depth of 21 feet below low-water mark. The channel to the port would have a width of 820 feet between the breakwater entrance and the port proper. The port would be excavated along the full length of the shore, and protected and enclosed by a pier 3,672 yards in length, following somewhat the outline of the shore, and forming one immense dock, divided into three smaller ones, by means of two moles run out from the shore to the east, in front of the Central Railway Station. Each of these moles would be 393 feet in width, the one 984 yards in length and the other 1,531 yards, and the width of the docks would be 656 feet in each case.

An account is given of the sundry works in connection with these docks, making provision for the quay, the wharves, and the drainage of the town and harbour. The time needed for the execution of this entire scheme is estimated at seven years, including a year for the construction of the necessary shops, &c. The total expenditure, exclusive of the lighthouses, bollards, buoys and similar apparatus is set down at £3,679,000.

It is pointed out by the commissioners that in its essential features this scheme coincides with that submitted by Mr. B. Caymari to the Government in 1889, and that it complies generally with the conditions laid down by the law of July 14, 1894.

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One of these, however, states that "the works ought to be planned so that they may be constructed in sections and extended at any future time if it were necessary." From a scrutiny of the scheme it appears to the commissioners that the project does not satisfactorily respond to the conditions imperatively and judiciously laid down in Art. 1 of the Law. Again, though it is asserted that the outer harbour works will shelter the bay and entrance channel from the south-west and south-east winds, it does not appear that the breakwater will effect this object to any extent, and the so-called "outer harbour" would more resemble a roadstead than an outer harbour. Various objections are urged to the great extent of space included within the proposed breakwaters, and likewise to their position, and it is hinted that such barriers would lead to the silting up of the port. The positions of the port dependencies and of the proposed careening-dock are also subjected to adverse criticism. Dealing next with the construction of the breakwaters and piers, it is explained that where the works have to be erected on sites where the bottom is of mud, the foundations of the breakwaters, piers, and wharves have to rest on a very wide formation, composed of two layers, the one of sand and the upper one of stone, but it is not specified whether this has simply to be executed on the natural bottom, or if dredging has first to be resorted to, in order to obtain a bottom of greater consistency upon which to work. The more perfect protection of the breakwater by means of rocks or loose stones on the sea side is insisted upon; the parapet, specially designed to obstruct the passage of the waves over the same, is objected to, and it is asserted that many minor details in the scheme are defective.

Passing on to the modifications proposed by the commission, which are shown on an amended plan, it is pointed out that since the business quarter of the city is found between the Custom House and the railway station, it is here that the port should be established, and all considerations would seem to indicate this part of the shore as the most appropriate site. The requisite conditions would be met by the construction of a quay-wall along the northern shore of the bay, from which would branch off a series of moles, the former following the normal direction of the shore, and the moles being in parallel alignment with the streets of the city. Moreover, situated here, the docks and moles would be entirely sheltered from the west, south-west, and south-east winds. In order to avoid disturbance of the waters in the bay by winds, and to prevent deposits of silt, an interior dock-wall or pier is proposed, which would be parallel with the quay-wall, and at a sufficient distance from it to allow of the construction of docks, having a width of 547 yards, more or less, between the shore quay and the outer quay, which latter may be built for the full length of the interior pier. The port would be closed on the west by a mole or pier, leaving an entrance proper of 328 feet in width. An entrance or passage of similar width might be left at the northern extremity to allow of the easy transit of tugs, or small steamers, and the other craft

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employed in lightering. It is of the first importance that the outer harbour should serve as a shelter for the entrance of the port, and it should be so arranged that whatever may be the state of the weather, vessels should be able to communicate with the port and effect their transhipping operations. It will, it is stated, best be formed by two rectilinear breakwaters, so placed as to afford shelter from the waves rolling up from east to west on the southern side. The eastern breakwater should start from Point Sarandi in direct continuation of the street so called, and it will thus form a prolongation of the ridge of the promontory on which the city stands. The western breakwater should be almost at right angles with the first, the included angle being 96°; the distance apart of the two extremities being 328 yards. The length of the eastern breakwater will be 787 yards, and that of the western one 1,290 yards, and they will terminate in 16·4 feet of water. The outer harbour, in which the large Atlantic liners, drawing 21 feet and more, and only remaining a few hours in Montevideo, will be able to anchor, would be excavated to a depth of 23 feet, and the channel leading to the same will be dredged to a similar depth. The outer harbour will have an area of 258 acres, available for vessels of 23 feet draught, although its total area will be much greater, taking into consideration the space in the bay to the north of the port, behind the shelter of the breakwater. The approach channel, connecting the entrance between the breakwaters and the line of 23-foot soundings, will have a minimum breadth of 656 feet, with an approximate length of 1½ mile, marked by buoys and lighted by oil-gas. Full particulars are given of the equipment of the port, of the position and construction of the quays and wharves, the railway service, and the general method of construction, together with a sketch of the possible future development of the port and the increase in the trade. Some details are given of the proposed machinery and apparatus needed, and an outline of the working regulations is suggested. The report concludes with a programme of the works to be at once executed, beginning with the two breakwaters, a portion of the interior dock-wall, five of the moles, with the adjacent wharves and quays, and a large careening dock 590 feet in length. At least six years will be needed for the execution of the works contemplated in the first instance, and the approximate estimate of the cost is £3,200,000, while the equipment will involve an additional expenditure of about £400,000.

G. R. R.

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*The Hamburg Petroleum Harbour.* By — WENDEMUTH.

(Deutsche Bauzeitung, April 29, 1896, p. 218.)

The first petroleum harbour at Hamburg was opened in 1879, and had a length of 1,083 feet (330 metres) and a breadth of 328 feet (100 metres). The storage room was sufficient for

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145,000 barrels, and at that time the whole of the petroleum was imported in barrels. In consequence of the construction of new docks it became necessary in 1891 to remove the petroleum store from the east to the west side of the harbour. As a precaution against the spread of fire the entrance of the petroleum harbour is closed with fire-proof pontoons, lined on the inner side with clinker brickwork. One of these, 78·74 feet (24 metres) long, is movable and remains open during the day, but is closed at night.

The first tank for storing petroleum in bulk was constructed in 1886, and had a capacity of 10,000 barrels. Two years later seven other tanks were erected. Until the end of 1894 the harbour was let to a contractor who had the exclusive right to store petroleum, charging according to a fixed tariff. Under the new contract private stores are allowed, and several firms have erected tanks.

The arrangement of the private tanks is similar to that of the public ones. The tank-steamers bringing the petroleum are moored at the end of the pipe-line leading to the storage-tanks. This is composed of wrought-iron pipes, 7·87 inches to 9·84 inches (200 to 250 millimetres) in diameter, through which the oil is pumped by means of the pumps with which most of the steamers are provided. In case of necessity steam can be supplied from a permanent boiler on shore, or a stationary duplex pump of a capacity of 550 gallons (2,500 litres) per minute can be used for drawing the oil out of the steamer and forcing it into the tanks. It was found necessary to sink this pump about 7 feet 6 inches below the quay-level, because petroleum cannot be raised higher than 23 feet (7 metres) by suction, on account of its tendency to give off gas under reduced pressure. The storage-tanks are connected by means of pipes with the department in which the casks are filled. After leaving the cooperage the casks are coated internally with glue, and are painted externally with a paint in which ultramarine and resin are the chief ingredients. The taps for filling the casks are automatic, cutting off the supply as soon as the cask is full. Few casks are stored on the spot; they are loaded into barges and forwarded to their destination when filled. There are thirteen tanks altogether, with a total storage capacity of 175,000 barrels.

In the construction of the tanks, the bottom, which is 0·35 inch (9 millimetres) thick, is packed upon wooden blocks at a height of 2 feet 7½ inches (80 centimetres) above ground-level. After it has been riveted and caulked, a temporary rim is attached in such a way that a layer of water, 11·8 inches (30 centimetres) deep, may be placed upon it. When this test has shown it to be watertight, the ground underneath is levelled and covered with a mixture of tar and sand. The bottom is then lowered upon this bedding and the erection of the tank continued. The upper ring of plates is first riveted together, and upon this the cover; this is then raised a short distance and the next ring of plates riveted to it, and so on, until the lowest ring of plates forms the junction between the sides and the bottom. The object of building down-

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wards is to enable the riveting to be carried out at ground-level. Double rows of rivets are used with all the newer tanks. Several manholes are provided for each tank. All but one of these are kept tightly closed, one being provided with a gas-cap through which the gases liberated in the contents of the tank by an increase of temperature can find an outlet. These gas-caps are constructed on the principle of a safety-lamp, having two internal caps of brass-wire gauze, and one external cap of iridium-wire gauze. By this means all differences of pressure between the interior of the tank and the atmosphere are obviated.

W. F. R.

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## *The Tequixquiac Tunnel.* By Luis Espinosa.

(Anales de la Asociación de Ingenieros y Arquitectos de Mexico, 1895, p. 3.)

This tunnel is intended to drain the bowl-shaped depression in which the city of Mexico is situated, and also Lake Texcoco. Two points were thought suitable, Huehuetoca and Tequixquiac, and the latter was chosen. The Tequixquiac site had occupied attention since 1600, when the first project was drawn up. The Author refers at some length to the dykes used by the Aztecs and the constant menace of inundations from Lake Texcoco; a great inundation took place from 1629 to 1634. A tunnel at Nochistongo had been made by Enrico Martinez, but was not sufficient for the purpose, and the Author gives details showing that the Tequixquiac position was more advantageous. Mr. Velasquez de Leon drew up a memorial on the subject in 1774. An error of 44 feet was found in the levels previously taken. The Author then quotes Mr. Velasquez at some length, thus explaining why the Tequixquiac site was selected.

He stated that a fall of 0·2 per 1000 was sufficient for the bed of the canal. In 1848 Mr. Smith, of the Engineers of the United States Army, was appointed to consider the question. He made his report, stating that Tequixquiac was the best site, and that no more lives and money should be spent in deepening the Nochistongo tunnel which would not serve the required purpose of draining the valley. The Author then quotes Mr. Smith's report at some length. Nothing was done by the Government, but in 1855 the city was menaced by a flood. A society of proprietors was formed and a prize of £2,400 offered for the best project of draining the valley. Seven projects were received, and that of Mr. Garay was awarded the premium, but it was not paid. In 1865 the lake began to rise again, and the Government ordered the line traced by Smith to be followed.

The tunnel finally projected began near the north side of the Zumpango lake and ended at the ravine of Acatlan, a length of 10,365 yards in a direction 16° west of north, and had an inclination of 1 per 1,000. There were twenty-four shafts at intervals of 435 yards, so that there were fifty working faces. The depths of

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the shafts varied from 32·75 to 106 yards, and the transverse section was 9·8 feet long by 6·5 feet wide.

The work was begun in the latter half of 1866, and was delayed at the beginning of 1867, and in eight months about 760 yards were sunk, or a little over half the total of 1,370 yards, no pumps being then found necessary. The engineer, Mr. Miguel Iglesias, left in 1866 for Europe to buy pumps and other apparatus. The Government ordered Mr. Garay to be paid the premium he had gained ten years before, but it is not stated whether this was actually done.

In 1867 the Imperial Government came to an end, and a little later the Republican form of Government was restored. Work was stopped and the whole matter reconsidered by a committee of engineers. In 1868, after much discussion, the work was continued at Tequixquiac under great financial difficulties, but came to a stop in 1871. The discharge cutting had been made, but instead of entailing an excavation of 495,000 cubic feet, it actually entailed removal of 13,200,000 cubic feet, owing to alterations in the dimensions. The discharge canal from San Lazaro in the city of Mexico was 52,800 yards long. The Author then describes in detail the various obstacles met with, and the cubic contents of the excavation, and a Table of the depths of the shafts is given. The pumps sent from Europe were insufficient to cope with the water, and the Author describes the plant provided; details are then given of the progress made in each shaft and the means used for coping with the water. In October, 1871, all work was suspended until 1885, owing to financial difficulties, except merely keeping in order the work which had been done. In the period from 1868 to 1871, no work at the tunnel proper had been done at all. It appeared that no calculations had been made as to the discharge capacity of the tunnel, and there was no certainty that it could deal with the quantity of water required. Garay made his calculations for a discharge of 1,240 cubic feet per second; Iglesias made other calculations, but both generalised from data of a single year. Based on observations over nine years, it was stated that a discharge of about 700 cubic feet per second would be enough. Details are then given of the annual rise of the lake, and it was finally decided that a discharge of 620 cubic feet per second should be arranged for, and an oval form was selected.

It was arranged to use an open canal 31 miles long, and then a tunnel 5·9 miles long; the canal was to have a fall of 0·185 per 1,000 and to cross four or five rivers by aqueducts.

Details then follow of the size of the section of the tunnel. The whole of this new project was approved in 1877, and particulars are given of the stone and brickwork. A great many political details are mixed up with the technical description. A vast number of different engineers were then consulted, and radical changes made in the programme. An English company then undertook the work, and the Mexican Government raised a loan in London. The contract price was £487,500 with a fine of £60 per

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day for each day over three years occupied in the work, and a bonus of the same amount for each day under the time. The prospecting company carried on work from 1889 to 1890, and then Messrs. Read and Campbell carried it on alone to October, 1891, when they gave it up, but undertook it again provisionally on new terms. The Author continues the disastrous history of the work down to the 10th June, 1893, dating the Paper from Zumpango; the work at that date was in an unfinished condition.

A Table is given at the end of the Paper showing the amount of material got out of the shafts and tunnel up to March, 1893, from which it appears that there then remained about as much to be done as was carried out in thirteen months, from March, 1892 to March, 1893.

E. R. D.

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## *Alterations to the Outfall Sluices of the Selzaete Canal.*

By CHARLES PIENS.

(Annales des Travaux Publics de Belgique, June, 1896, p. 357.)

The Selzaete Canal, about 23½ miles long, was constructed in 1848 to drain the east of Flanders, and has its outfall in the North Sea near Heyst and Lisseweghe. This outfall is regulated by four openings, 19 feet 8 inches wide, each opening being originally controlled by three pairs of gates, one for the ebb and two for the flow. The inner ebb-tide gates were only fully opened on rare occasions, the outflow being generally regulated by sluices in the leaves of the gates. Of the outer pairs of gates, that nearest the sea was usually the only one used, the other being for use in case of emergency. These outer gates were opened by the pressure of the canal water, as soon as the level of the sea fell below that of the canal, thus allowing the land-water to escape; and they closed by themselves as soon as the sea-level rose again up to or above the canal-level. In rough weather, however, it was found that the action of the waves closed the gates with a certain amount of shock, and that they opened and closed several times until the level of the outside water was decidedly above that inside; while during stormy weather this action of the waves was sometimes so violent as to split the meeting posts and otherwise damage the structure.

Various means were tried in order to prevent this action on the gates, but without success, until finally the Author designed an alteration of the outfall, substituting lifting sluices in place of the opening gates; and in the Paper here referred to he details the considerations on which his designs are based.

He placed a lintel over each of the four openings, which he divided into three by means of metal verticals 10⅝ inches wide, the centre of these three smaller openings being 6 feet 1½ inch wide, the side ones 5 feet 10⅝ inches wide, and the shuttles for

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closing all of them being 6 feet 9½ inches wide. The height of the shuttles was 13 feet 11¼ inches, and their thickness 6¼ inches, the level of the underside of the lintel being 13 feet 3½ inches above sill-level, or at the highest known level of the water in the canal.

The Author then gives his calculations for the strength of these shuttles and the other portions of the structure. The shuttles do not touch the lintel, but the space at the top is closed by a strip of india-rubber fixed on the shuttle and pressed against the face of the lintel when the sea-water rises above the tops of the shuttles. The gross weight of each shuttle with its lifting rack is about 43½ cwt., but this is reduced in water to a little less than 16 cwt. The weight of the counterpoise is 16 cwt., and the Author next proceeds to estimate the resistance to be overcome when opening and closing the sluices. He assumes that if the first sluice be raised when the water inside and outside the canal is at the same level, the last sluice will be raised thirty minutes later, or when the sea-level has fallen 19½ inches. He considers the pressure on the sluice under various conditions of waves, and thus arrives at a maximum of resistance to opening of 88 cwt., and to closing of 98 cwt. in stormy weather. He quotes instances of sluice-lifting winches, and the power required to work them, at Ypres, Furnes and Nieuport, and from these he decided to adopt a reduction of 200 to 1 in the gearing of the winches, and assumes that the internal friction of the winch will be equivalent to 15½ lbs. on the handle. Thus, for opening the sluices, he estimates that from 31 lbs. to 64 lbs. is required on the crank, according to the position of the shuttle and the state of the sea, while for closing the force required varies from nothing to 69½ lbs. The winches are designed so that all the axles are in one horizontal plane, and accessible by unbolting the top of the box in which they are enclosed. The gearing is all of cast steel. Should it be found that this arrangement is not sufficiently powerful to lift and lower the sluice shuttles with the requisite speed under all conditions of working, the Author proposes to increase the weight of the counterpoise to 43½ cwt., and while the sluices are open, to raise these counterweights, so that the whole weight of the shuttles may be available to assist in their closing. The winches are intended to be worked by one man, but two handles are provided to each.

The article is illustrated by two plates and nine small cuts in the letterpress.

R. B. M.

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*Sluice-Shuttles on Rollers, with Ball-Bearings.* By — WENDER.

(Annales des Ponts et Chaussées, April, 1896, p. 516.)

In this article the Author, after some introductory remarks on sluices in general, describes some experiments with sluice-shuttles on rollers, made at the Marolles Weir, 5 miles above Montereau, in April, 1895. The sluices at present used at this dam are timber

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needles, 3½ inches square and 13 feet long, the height from sill to upper bar being 11 feet 1¾ inches.

For the experiments, special steel frames forming two sluice openings were made and fixed in the weir. These had a batter on the up-stream side of one in ten, and the bearing face was composed of two steel angles and a projecting web-plate, the angles forming the ways for the rollers of the shuttles and the web the division between the adjacent sluices. The shuttles were of 1¾-inch planking, tongued and grooved, 3 feet 6¼ inches wide with heights of 11¾ inches, 15¾ inches and 19¾ inches. They were stiffened on the back with battens, and were provided with a V-shaped handle bar. On each corner of the down-stream face was fitted a steel roller, 1½ inches diameter, in a steel box and with ball-bearings; and on each end were two brass rollers, 1 inch diameter, with ordinary pin-bearings. The steel rollers ran on the angle bars of the steel sluice frames, and had a clearance, between the frame and the face of the shuttle, of 0·16 inch. The shuttles in length had a clearance of 0·35 inch between the web-plates of the frames at each end, and the 1-inch rollers projected 0·12 inch beyond the timber.

The shuttles were put in place and removed by means of a hook, somewhat resembling a boat-hook, and rested one on the top of the other to the required height. They could be lifted in and out with ease by one man; and, when the head of water was small, would run to the bottom of the frame by their own weight, while, with a fall of 7 feet 3¾ inches, two sets, each of eight shuttles and a top regulating board 7¾ inches deep, were taken out and replaced by one man in four minutes. The heights of these eight shuttles were: one 19¾ inches, three 15¾ inches, and four 11¾ inches, or a total height of 9 feet 6 inches exclusive of the regulating board.

The Author states that, with ordinary care, no trouble is experienced from rust on the ball-bearings, and is of opinion that the leakage due to the clearance for the rollers on the pressure face is not greater than that with ordinary sluices of the needle type. He concludes with the following recommendations:

(1) All the sluice openings in a weir should be of the same width, so that all the shuttles may be interchangeable.

(2) The height of the shuttles should be between 16 inches and 20 inches; narrower than this they are liable to jam, and wider, they become too heavy for convenient handling.

(3) The roller boxes must be very carefully fixed so that the rollers have a uniform clearance beyond the shuttle face of from 0·12 inch to 0·16 inch; and these roller boxes should be so arranged that the clearance is not affected by the swelling of the wood.

A sheet of detail drawings is appended to the Paper, which fully illustrate the construction of the sluices and rollers.

R. B. M.

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## *The Water-Supply of Quimper.* By A. Considère.

(Annales des Ponts et Chaussées, April, 1896, p. 495.)

The village of Quimper (Brittany), with a population of 17,500, was, up to 1894, very poorly supplied with water, the pipe-service from the stream Pratmaria at times only supplying at the rate of half a gallon per head per day. Mr. Soulié was therefore requested to prepare a scheme, similar to that carried out at Rennes, for collecting water by means of underground channels.

The country around Quimper is granitic, and the Author describes the nature of the soil overlying the rock, which is seldom more than 23 feet below the surface of the ground. Down and into this solid rock trenches were cut and channels formed with blocks of stone, the lower blocks being laid dry and the upper ones set in cement mortar, the portion of the trench in the rock above the top of the channel being filled in with cement concrete, rendered on its upper surface with rich cement mortar. Above this the trench, partly in the rock and partly in the overlying soil, was filled in for a depth of about 2 feet 7 inches with clean silicious sea-sand, the excavated material from the trench being then filled in to the ground-level. The object of this arrangement was to ensure that all surface-water should filter through the subsoil overlying the granite, and only gain access to the channel by means of the fine crevices in the rock itself. By this means the water collected by the channels was very thoroughly purified from organic and other foreign matter. To further ensure the purity of the water, the town acquired the fields in which the channels are constructed, and these are let on condition that only mineral manure is used on them.

The catchment area is 618 acres, and the minimum yield, on the 30th September, 1895, at the end of an exceptionally dry season, was 263,500 gallons, while the maximum obtained was 831,800 gallons—on the 19th January of the same year. The minimum is equivalent to 427 gallons per acre, Mr. Soulié's estimate being only 267 to 311 gallons per acre, and the rainfall being from 39 inches to 47 inches per annum. The total length of the channels is 2,047 yards, but for 875 yards of this length, on the lower portion of the work, ordinary watertight conduits could have been substituted without appreciably reducing the amount of water collected. The average depth of the trenches was 13 feet below ground-level, and the cost was 18*s.* 11¾*d.* per yard, made up as follows:—Excavation, 4*s.* 10¾*d.*; construction of channel (9·8 inches by 11·8 inches), 8*s.* 8½*d.* per yard; sand-filling, including carriage, 3*s.* 4*d.*; filling in and ramming in 8-inch layers, 2*s.* 0½*d.*; the prices for masonry per cubic yard were—dry masonry, 4*s.* 6½*d.*; masonry in cement, 13*s.* 7¾*d.*; concrete filling with rendered face, 18*s.* 2½*d.* The additional cost of manholes, clearing out the channel, &c., amounted to 2*s.* 4¼*d.* per yard forward, or a total cost of £1 1*s.* 4*d.*

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per yard of channel. This does not include the cost of the land, nor the construction of the conduits from the collecting channels to the reservoir, nor the reservoir itself; but the construction of these offers no points of special interest. There are six illustrative cuts in the body of the article.

R. B. M.

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## *Queen Land Division of the Philadelphia Waterworks.*

By J. E. CODMAN and T. H. MIRKIL.

(Proceedings of the Engineers' Club of Philadelphia, April, 1896, p. 35.)

A description is given of the boilers, engines, and pumps at the above pumping-station, which are designed to lift 66,640,000 gallons of water per twenty-four hours to a height of 225 feet.

There are twenty-four boilers arranged in four batteries of six, each capable of evaporating 5,000 lbs. of water per hour into dry steam. They are 8 feet 6 inches diameter and 20 feet long. In one half of their length are fixed two horizontal Fox's corrugated furnace-flues, and from the ends of these, in the other half, ninety 4-inch tubes, also level. The gases pass from the fire-grates through the tubes, and then underneath the boilers to the chimney-flue. Twelve 2½ inch stay-bolts run from end to end of the boilers. The boiler-plates for the shell are made of steel $\frac{7}{16}$-inch thick, the ends $\frac{5}{8}$-inch and the corrugated flues $\frac{17}{32}$-inch thick. The horizontal seams are butt-jointed and triple-riveted, with inside and outside cover-plates and the circumferential joints double riveted. They were all tested to 220 lbs. on the square inch. The steel plates were specified to stand an ultimate tensile stress of 50,000 to 60,000 lbs. per square inch with an elongation of 25 per cent. in 8 inches, and a reduction of area of not less than 50 per cent.

The engines are four in number, of the vertical triple-expansion type, each has therefore to lift 16,660,000 gallons of water per day through a 48-inch diameter pipe, 8,000 feet long, against a pressure of 110 lbs. per square inch, allowing for friction. The high-pressure cylinders are 37 inches diameter, the intermediate 62 inches and the low-pressure 96 inches diameter, and all have a stroke of 54 inches. Each engine has two fly-wheels 18 feet diameter, each weighing 40,000 lbs., and they work at the rate of 22½ revolutions per minute. The steam valves are of the gridiron slide pattern actuated by cams with quick opening and closing movements. The high-pressure cylinder takes steam at 140 lbs. pressure, the steam inlet being 8 inches diameter. All the cylinders are steam-jacketed with steam from the boilers and have reheaters between the cylinders. The air-pump is single-acting, and has a diameter of 28 inches and a 36-inch stroke. The

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engines are supported on a steel structure instead of masonry, and the cylinders are alongside each other.

There are three single-acting plunger-pumps to each engine, all 34½ inches diameter, and stroke same as the engine. The suction-pipes are 300 feet long and rise 17 feet; they are 48 inches diameter and are provided with foot valves. The delivery-pipes are likewise 48 inches diameter and provided with check-valves. Each pump has ninety suction-, and ninety discharge-valves, 9 inches in area.

The duty of the engine and pumps is 123,000,000 foot-pounds per cwt. of coal.

A. W. B.

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## *The Waterworks of Astoria, Oregon.*

By A. L. Adams, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, April, 1896, p. 201.)

Astoria is situated on the south bank of the River Columbia, 12 miles above its mouth. In 1883 the Columbia Water Company constructed works to utilize the water of Bear Creek, a mountain stream flowing into the River Columbia, 7 miles above the town. The water was conducted to the town through a welded wrought-iron pipe, which terminated at a reservoir of 420,000 gallons capacity. Owing to faulty alignment these works delivered less than 70 per cent. of the quantity of water they should have done. In 1891 the old works were purchased by the Board of Water Commissioners established by an Act of the State Legislature. In 1894 they resolved to construct a new system of supply. The new intake was 1 mile farther up-stream, the drainage area above that point being 4·82 square miles. The yield varies from 2,000,000 to 25,000,000 gallons per day, the smallness in the variation being due to the thick vegetation retarding the flow off of the rain. The amount of the supply fixed upon was 3,333,000 gallons per day. A weir delivers the water into a receiving basin from which it enters the line of pipes. The latter consists of 7½ miles of wooden stave pipes,[1] 18 inches diameter; 3 miles of steel pipes, 16 inches diameter, and 1 mile 14 inches diameter, and delivers into a service reservoir capable of holding 5,400,000 gallons. The wooden pipes are nearly 50 per cent. cheaper than the steel pipes of the same carrying capacity. The maximum head for which the former are employed is 150 feet, while for the steel pipes it amounts to nearly double that amount. The staves must be thin anough to allow of complete saturation, and to bend readily to the curvature employed, but thick enough to prevent undue percolation. The steel bands must be of such a size, and so spaced, as to secure the desired factor of safety against

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 430.



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rupture when the swelling of the wood is taken into account, also to prevent any sensible flexure in, or destructive crushing of, the fibres of the staves. The latter were made from 6 inches × 2 inches yellow pine, free from knots, shaped to the circles, and $1\frac{3}{8}$ inch thick when finished; along one radial face is a bead. Their lengths varied from 12 feet to 24 feet, and tongues of band steel were used to make the butt joints. The bands were made of $\frac{7}{16}$-inch round steel, spaced 12 inches apart for low heads, varying to $2\frac{1}{2}$ inches apart for a head of 150 feet.

Careful experiments showed that the maximum compressive stress the wooden staves can resist is 150 lbs. per square inch. With only a small initial stress the swelling of the staves alone, when wetted, is capable of developing a temporary stress of 125 lbs. per square inch.

The following experiments were made on the loss of head due to friction in the two kinds of pipes :—

| Kind of Pipe. | Diameter. | Discharge. | Virtual Gradient. | Value of Coefficient "c" in Chezy Formula $v = c\sqrt{rs}$. | Value of $r$ in Kutter's Formula. |
|---|---|---|---|---|---|
| | Inches. | Cubic Feet per Second. | Fall per 1,000 Feet. | | |
| Wooden stave | 18 | 6369·0 | 1·9628 | 132·88 | 0·0098 |
| Steel . . . | 16 | 6369·0 | 5·0023 | 109·80 | 0·0113 |

A feature in the distribution is that, in case of fire, water from the high-pressure zone can be turned into the low-pressure zone by means of a cock at the central fire station. The spindle of the valve admitting the high-pressure water is attached to a piston working in a cylinder with the high-pressure water on both sides of the piston. Under ordinary circumstances the valve is kept shut by means of a spring; but if the cock at the fire station on a small pipe, which leads from the upper side of the piston, be opened the piston rises and admits the high-pressure water to the low-pressure system; when this cock is again shut the valve closes.

A. W. B.

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*The Purification of the Subsoil.* By H. Koschmieder.

(Gesundheits-Ingenieur, 1896, p. 192.)

In the case of the recent cholera epidemic at Hamburg the various precautionary measures adopted proved ineffectual in combating the disease, and, notwithstanding the assertions of the advocates of the contagious theory of the outbreak, the opinions of the believers in the epidemiological theory maintained by Prof. v. Pettenkofer have gained ground. In accordance with the

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latter view, the chief remedial measures requisite are the thorough purification of the vicinity of human dwellings by means of sewerage, house-drainage, and the provision of an ample supply of pure water, not merely for drinking purposes but also for cleansing and other domestic uses. If the prevalent conditions in these respects are examined, it will be found that, while considerable progress has been made in certain of the larger towns, there are still many places in which all sanitary precautions have been lamentably neglected. In such cases the soakage from cesspools, the leakage from badly-laid pervious drains, and the liquid portions of human and animal dejections find their way into the sub-soil and constitute a perpetual menace to the salubrity of the inhabitants. Even in the more important towns where the requisite works have been carried out, and where the further pollution of the soil is prevented, it is necessary that the animal matters absorbed into the ground in the period antecedent to the construction of the drainage works should be got rid of, and this can only be effected when they have become thoroughly mineralised. This process is mainly accomplished by the natural ventilation caused by the periodical fluctuations in the level of the sub-soil water, the air being drawn down as the water sinks and expelled as it rises. The tendency, however, in towns is to cover the street surface with asphalt, or other impervious materials, and to provide for the foot passengers pavements of concrete or large slabs of stone carefully jointed with cement. The proper access of the air to the soil, when the level of the water therein falls, is hindered and the egress of the same is prevented over the entire area of the street. As a necessary consequence the foul emanations are often driven into the cellars and basements of the houses and give rise to bad odours and vitiated air in the house itself. The process of putrefaction of polluting matters in the sub-soil may go on throughout long periods, and may also lead to very serious contamination of the water which exists in the upper layers and finds its way into wells and springs.

The Author discusses the effects of these evils and points out that it would be expedient when streets are being paved with impervious materials to provide ample ventilation for the soil itself, which could readily be arranged by suitable openings and gratings, or the foot pavements might be formed of porous substances. In this way the air could find an easy entrance and exit and the ventilation of the sub-soil could be assured. The planting of trees would also constitute a valuable remedial measure, and this should be resorted to wherever possible in towns.

G. R. R.

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## *On the Nature and Treatment of Ferruginous Subsoil Water.*

By Prof. Dr. DUNBAR.

(Zeitschrift für Hygiene, 1896, p. 68.)

Surface water, from its very surroundings and uses, is liable to contaminations which, notwithstanding sand-filtration or, in the case of running water, the tendency always present to self-purification, may at times be fraught with danger to consumers. Owing to these considerations, efforts are constantly being made to obtain from the deeper strata a supply of water free from infectious matters, and therefore not liable to suspicion, and water procured from a sufficient depth possesses these qualifications and, being moreover of even temperature throughout the year, is refreshing and palatable. Some of the difficulties encountered in obtaining an adequate supply of water in this way for the use of towns are discussed, as also the character of the water itself, which in certain cases, owing to its hardness or its ferruginous properties, has been proved to be unsuitable. This latter objection was at one time thought to be insuperable, but recent experiments, beginning with those of Salbach at Halle in 1868, have proved that by means of aeration and filtration such waters may be freed from iron and rendered clear and sparkling.

The process of removing the iron has been carried out upon a large scale at Charlottenburg, Leipzig, Kiel, Trier, and other towns with marked success, and many other localities where the water is rich in iron are taking measures to avail themselves of this treatment. The Author remarks that, while the plans hitherto adopted can readily be carried out for large supplies, a difficulty arises in the case of small springs or wells used for a single household, and he has therefore paid special attention to the question of how small quantities may best be dealt with, which is one of considerable importance for the population of the marshy districts of Northern Germany.

An account is given of the results obtained by previous investigators; thus Anklam, whose attention had been called by Finkener in 1880 to the scarcity of oxygen in ferruginous water, carried out some experiments in the precipitation of the iron by means of the oxygen in the atmosphere. In the course of observations which extended over a whole year, he, in all cases, obtained a water nearly free from iron which remained perfectly clear and devoid of any growth of the crenothrix.

In 1890 Proskauer pointed out that the iron was nearly all of it present in sub-soil water containing carbon dioxide as free dissolved ferrous carbonate, with a little iron phosphate. Substances containing humus have the property of increasing the amount of iron present, because they have a tendency to form soluble compounds with the iron. By means of oxidation the insoluble ferric salts are formed, and in the course of this process the oxygen in

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the atmosphere displaces the uncombined carbon dioxide. Proskauer was of the opinion that the presence of a considerable proportion of carbon dioxide was no bar to the separation of the iron, thus differing from those writers who maintain that the iron can only be removed when the bulk of the carbon dioxide has been expelled.

Piefke coincides in the main with Proskauer and considers that, owing to the presence of the carbon dioxide, sub-soil water has the property of dissolving the ferrous-carbonate, and he holds that the amount of organic matter existing in the water has some influence on this action. Fisher combats the opinion of Piefke that the separation of the iron goes on *pari passu* with the expulsion of the carbon dioxide, and that this gas has a direct influence upon the reaction, since he found that the bulk of the iron was removed in from two hours to three hours, whereas the carbon dioxide disappeared much more slowly, and he came to the conclusion that the expulsion of the carbon dioxide was of no importance in so far as the spontaneous separation of the iron was concerned, and that the reaction was solely due to the absorption of oxygen. Lübbert maintained that the initial opalescence leading to the subsequent precipitate, which Piefke held to be due to the ferrous carbonate, was a sign that the complete oxidation had been effected; but since the opalescence began, in the case of his experiments, in the deepest part of the liquid, before the oxygen in the atmosphere could have penetrated to this point, there must have been oxygen already present in the water which could not come into action so long as the amount of carbon dioxide present was sufficiently great to hinder the oxidation. When in Lübbert's experiments the water was exposed to an atmosphere of nitrogen or hydrogen, the liquid still became cloudy because the carbon dioxide was able to escape, but when the atmosphere above it was one of carbon dioxide the water remained clear. Lübbert therefore maintained that the phenomenon depended upon the tension of the dissolved carbon dioxide.

From the experiments now recorded it is clear that if Lübbert's observations are correct they are not in all cases applicable, and each class of ferruginous waters must be specially studied. Those examined by the Author and first described were obtained from a tube-well about 32·8 feet below the zero point of the Hamburg survey, or at a depth of about 57 feet from the ground-level. The water at the time it was drawn was perfectly clear and of a slightly greenish tinge, and, though it smelt strongly of sulphuretted hydrogen, it showed no reaction with lead paper. The taste of the water was affected by this gas and by the presence of iron and was mawkish and ink-like. The water at times turned blue litmus-paper red, at others the litmus was coloured blue. A complete analysis is given, and when examined bacteriologically it contained four germs per cubic centimetre.

A description follows of the behaviour of the water when drawn and examined in a glass vessel; the separation of the iron causing

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at first turbidity, but subsequently giving rise to the formation of a precipitate, due, as the Author shows, to the action of oxygen and not to the separation of the carbonate of the protoxide of iron. It became necessary, therefore, to obtain a sample of the water which had been kept free from contact with the atmosphere, and this was impossible with an ordinary pump. Special arrangements were accordingly made, by the use of pipettes, to obtain samples which neither in the well itself, nor in bringing the water to the surface, had been exposed to the air, and it was then found that the sample could be kept unchanged for any length of time in stoppered bottles. A number of experiments were made in Petri-Maassen flasks with various samples, and the gases absorbed and given off by known volumes of the water were measured and recorded; illustrations are given of the apparatus employed. The general result was that the oxygen in the air is shown to be the chief agent, but that the carbon dioxide in the water is an important factor in facilitating the process of the expulsion of the iron.

Subsequent experiments were made by extracting the gases in the water with a mercurial pump, all contact with atmospheric air being prevented. The ferruginous water thus treated became at first cloudy and then milky, but careful tests indicated the absence of ferric salts. Water from which the iron had thus been separated by the vacuum action described was, however, by no means freed from all the iron. The Author's tests led him to conclude that the presence of carbon dioxide in the water had a powerful effect in hindering the oxidation of the iron compounds, but that even if the water is saturated with that gas the oxidation is not wholly prevented. Exposure to the air is necessary for the formation of ferric salts.

Another set of tests was made with artesian well-water, obtained at a depth of 640 feet below the surface, and similar results were obtained. The two sets of samples in question represent the extreme differences which occur in the sub-soil water, rich in iron, in the vicinity of Hamburg; the former serving as a type of the most impure and the latter may be regarded as the best quality of ferruginous water met with in practice. The effects of aeration on both these qualities of water are discussed and explained by reference to a series of Tables.

A special description follows of the aeration by the use of a coke-tower advocated by Piefke, with subsequent filtration as a means of purifying iron water. An account is given of Kröhnke's process for the removal of iron, which consists in the addition of lime and persulphate of iron to the water, combined with upward filtration, but Pelligot obtained very good results with iron chloride. The Author explains the efficacy of this treatment upon the samples of water investigated by him, and describes the apparatus employed by reference to diagrams. The system of treatment recommended by Steckel[1] is also examined, and several

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 490.

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varieties of common domestic filters were tested in which animal charcoal is employed. The Author states in conclusion that there are many processes available for the removal of iron upon a small scale which render the use of ferruginous water possible in all cases likely to occur in practice.

G. R. R.

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## *Duncker's Apparatus for the Measurement of Moisture in Steam.*

By Dr. W. DREYER.

(Zeitschrift für Hygiene, 1896, p. 314.)

An outline is given of the conditions under which successful disinfection by means of steam is possible, and the need of the use of the signalling contact-thermometer, or of an apparatus such as that of Duncker is explained. By means of this latter contrivance it is affirmed that it is possible to indicate the existence of actually dry steam at a temperature of 100° C. in the middle of closely-packed bundles of linen, bedding, etc., undergoing disinfection. The more recent form of Duncker's instrument consists essentially of short lengths of catgut, prepared in such a way that they will only contract to the necessary extent in dry steam of known temperature, and thereby close an electrical circuit and give an alarm signal. For the purposes of disinfection two qualities of catgut filaments are prepared, namely, first, such as will contract to the requisite amount after exposure for four or five minutes to dry saturated steam at a temperature of 99° to 100° C., and secondly, those which will only contract to the necessary degree when exposed for a similar interval to dry steam at 102° to 103° C. The Author states that if this instrument was really possessed of these properties it would afford a most valuable means of control in cases of disinfection, but the experiments of Sander and Clarenbach,[1] and those of Dräer, do not confirm the claims put forward by the inventor and the favourable opinion of the instrument expressed by Rohrbeck. The method of investigation pursued by these authorities is discussed, and it appeared advisable to undertake a further series of tests to decide the matter conclusively. An outline is given of the various experiments needed to set at rest this question, and among other points to be examined were the following:—The accurate measurement of the length and thickness of the filaments supplied for use; the determination of the difference in the results occasioned by variations in the size of the filaments; to ascertain what difference in time would occur in giving the signal in the case of two instruments of precisely the same make placed side by side; to investigate the causes of certain functional irregularities in working; to determine whether the

[1] Minutes of Proceedings Inst. C.E., vol. cxvi. p. 432.

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apparatus does indeed, after an interval of five minutes, announce the existence of actually dry steam at a temperature of 99° to 100°, no admixture of air being present; and, lastly, to decide whether, as asserted by the inventor, the action of steam given off by water, boiling freely at 100° C., at normal atmospheric pressure, in the centre of the objects to be disinfected, is insufficient of itself to produce effectual disinfection.

The tests were carried out in special apparatus which is here described, and the various points were investigated in detail. The results obtained are set forth in Tables and are summed up in conclusion as follows:—Though considerable variations occur in the size of the fibres, these do not to any serious extent interfere with the accurate registration of the instrument. Three principal causes conspire to hinder the true working of the apparatus: a premature signal may be given by a false contact between the slide holding the filament and the metal frame of the instrument, or the hygroscopic fibre may be affected by moisture, or, lastly, the points of contact may become coated with oxide and thus delay the signal. Damp, moist air at a temperature of from 80° to 95° C. may cause the filament to contract and close the circuit. It was also ascertained that a signal may be given before the instrument has been exposed for several minutes to saturated steam, freed from air, and at a temperature of 99° to 100°. It was likewise possible to obtain complete, effectual disinfection, *i.e.*, the destruction of certain specified bacteriological tests, before the apparatus gave any signal whatever that the requisite temperature had been reached. The contact thermometer showed itself in all cases to be more reliable than the instrument for determining the moisture present in the steam. The Author states that his experiments, taken as a whole, confirm the objections which have been made as to the accurate working of the apparatus in question.

G. R. R.

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## *The Use of Formic Aldehyde Gas for the Disinfection of Large Apartments.*[1] By Prof. Dr. E. Pfuhl.

(Zeitschrift für Hygiene, 1896, p. 339.)

It is pointed out that the present methods of disinfecting dwellings give rise to much inconvenience to the occupiers, and that the gaseous matters which have from time to time been advocated for this purpose, such as sulphurous-acid gas and chlorine gas, have not proved wholly trustworthy. Much hope has therefore been placed in formic aldehyde gas, concerning which very favourable opinions have been expressed by Miquel, Philipp and Oehmichen; though Ascoli states that good results cannot be attained

[1] Minutes of Proceedings Inst. C.E., vol. cxxv. p. 471.

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by the use of the vapour of formalin, because of the difficulty experienced in distributing the gas equally throughout all parts of the room, and because, moreover, a portion of the volatile aldehydes evolved assume polymeric forms which may have no bactericide action. Recently attempts have been made to attain a more rapid and abundant evolution of the formic aldehyde than was possible by the use of formalin. This has been accomplished by the imperfect combustion of methyl-alcohol in specially constructed lamps. The Author refers to the experiments of Dieudonné with a lamp made by Tollens, and later with one manufactured by Krell, and he explains that having been entrusted by the Prussian War Minister to carry out a series of investigations into the use of this gas, he communicated with Dieudonné and obtained a series of lamps in October, 1895, and in February of the present year. An explanation is given of the construction of these lamps, which had each a capacity of 200 cubic centimetres, and an account follows of their use under various conditions set forth by the Author. The three hospital rooms in which the tests were made contained respectively 9,286, 3,248 and 2,118 cubic feet; the first served for seven beds, the second for three, and the third could if the necessity arose be used for two beds. The furniture and all the contents remained undisturbed during the trials, and were in no case injured in any way by the formic aldehyde gas. The test objects (infectious matters) were placed about the rooms, on the tables and on the floor, in open glass vessels, and they consisted for the most part of such matters as would commonly occur in rooms which required to be disinfected, such as tuberculous sputa, both fresh and dried, and also pure cultures of typhoid-, cholera-, diphtheria- and other bacilli, some being in the form of fresh agar-cultivations and some dried upon silk threads. To avoid a loss of the gas in consequence of the imperfect fitting of the doors and windows, certain of the chief crevices were pasted up. The vapours were allowed as a rule to stand in the rooms for twenty to twenty-one hours, though in a few instances the experiment only lasted for fifteen hours. The number of lamps used, the weight of methyl-alcohol utilized, and the effects upon the various test objects are set forth in Tables. The trial of the room containing 9,286 cubic feet, for which eighteen lamps were employed, was a failure, and no results are in this case published. A maximum of eight lamps was used in the room containing 3,248 cubic feet, and 5·4 grains of methyl-alcohol per cubic foot of space were consumed, but much larger quantities were employed in some of the smaller wards in which tests were made. Certain difficulties which arose in carrying out the process induced the Author to suggest the construction of more powerful lamps in which larger volumes could be volatilized, or, as is pointed out, it would be much more convenient if the gas could be liquefied in the same way as carbonic acid and sulphurous-acid gases, and could then be conveyed into the rooms to be disinfected, but this at present does not appear possible. As the

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result of his tests, the Author states that he does not think this gas can be employed with useful results in the disinfection of large spaces, and in this view he is confirmed by the recently published experiments of G. Roux and A. Trillat, who were unable by the use of a Bardet-Trillat apparatus, consuming 8·8 pints of methyl-alcohol, to disinfect with success a room containing 2,754 cubic feet.

G. R. R.

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*Electric Traction in the Paris Sewers.* By A. Dumas.

(Le Génie Civil, 18 July, 1896, p. 177.)

The main sewers of Paris are periodically cleared by means of scrapers carried on cars or boats.[1] These conveyances are also used for conveying visitors through the larger sewers under the Rue de Rivoli and the Boulevards de Sebastopol and de Malesherbes. These expeditions take place fourteen times a year, in spring and autumn, and about 8,400 visitors are admitted yearly. Until 1894 these cars and boats were drawn by men, but the labour and expense were found to be so excessive that now the traction is entirely done by electric motors, taking current from accumulator batteries on the boats or cars.

These main sewers are in section very similar to an ordinary tunnel; but in the floor is formed the rectangular channel for the sewage, while round the roof are fixed the water and compressed-air mains, the telegraph and telephone wires, &c.

The sewer under the Boulevard des Malesherbes is the largest; it is 18 feet 4½ inches wide, 10 feet high from floor to roof; and the sewage channel in the floor is 3 feet 5¼ inches deep and 9 feet 10 inches wide. Boats are used in this channel. The other sewers are smaller, the channels in them being only 3 feet 11 inches wide, and from 3 feet 11 inches to 5 feet 7 inches deep. In these, cars are run, the flanged wheels of the cars running on the edges of the channel, which are protected by angle-bars and form the rails. The approximate weight of a train of five cars, with 100 passengers on board, is about 7 tons 12 cwt., and this travels at the rate of about 3¾ miles per hour. The accumulator battery consists of twenty-eight elements, and weighs 14 cwt., and its capacity is 100 ampere-hours, with a mean discharge of 25 amperes at 50 or 60 volts. The motor, which is series-wound, develops 2 HP., and runs at 1,600 revolutions per minute, this speed being reduced to 80 by means of a pinion and wheel, and chain-gearing to the driving-axle, the wheels being 15¾ inches in diameter on the tread.

The boats are towed by means of a chain sunk in the sewage channel, which is brought to the surface and passes round a pulley

[1] Le Génie Civil, vol. xxviii. p. 262.

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driven by means of a double reduction gear from the motor. The chain, by means of guide-pulleys, makes three-quarters of a turn round the driving-pulley, this pulley being a magnetic one, magnetised by means of two coils, one on each side of it on the axle.[1] Each passenger train consists of six boats, in the first of which is carried the accumulator battery and a towing apparatus; while in the last boat, which is smaller, there is another towing apparatus. The battery consists of sixty elements, giving an output of 60 amperes for 2½ hours, at from 98 to 125 volts; it is divided into two parts, which can be connected in series or parallel as required. The motors run at 580 revolutions per minute; but this speed is reduced by means of the gearing, so that the boats travel at about 1½ mile per hour. The power required for this is from about 2 HP. to 5½ HP., according as the boats are travelling with or against the current.

The total length of sewers open in this way to the public is about 2 miles, and they are lighted partly by lamps on the foot-paths, or by oil-lamps on the boats.

The article is illustrated by a sheet of details of the boat machinery, and by details of the cars; and a sketch-map and sections of the sewers in the body of the Paper.

R. B. M.

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## *The Bernese-Oberland Railway.* By E. Strub.

(Schweizerische Bauzeitung, 1895, vol. xxv. p. 51 *et seq.*[2])

The Author gives a general description of the Bernese-Oberland Railway, which comprises, first, the line running from East Interlaken (Zollhaus) to Grindelwald, following the valley of the River Lütschine, passing the villages of Wilderswyl and Gsteig to Zweilütschinen, where it bends eastwards and runs up the valley of the Black Lütschine, passing Lütschenthal and Burglauenen to its terminus at Grindelwald; second, a line leaving the above at Zweilütschinen and running direct south, up the valley of the White Lütschine to Lauterbrunnen, where it terminates and the Wengernalp Railway[3] begins. The latter line runs from Lauterbrunnen to Grindelwald, via the Scheidegg summit.

In this way alternative routes are formed between Zweilütschinen and Grindelwald, viz., by the more direct low level line, via the valley of the Black Lütschine or by the high level line, via Lauterbrunnen and the Scheidegg summit of the Wengernalp. There are two other short mountain lines connecting with the Bernese-Oberland Railway, viz., one the Schynigen Platte Railway, which branches off to the east at Wilderswyl, about 1⅞ mile

[1] Le Génie Civil, vol. xxii. p. 58.

[2] These articles have been collected and published in pamphlet form by the Author.

[3] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 446.

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from Interlaken, and another the Lauterbrunnen-Mürren Railway, branching off at Lauterbrunnen and running southwards. These lines are all shown on a general map of the Bernese-Oberland district to a scale of 1 : 100,000. There is a longitudinal section given of the line between Interlaken, Wilderswyl, Gsteig, Zweilütschinen and Lauterbrunnen, a length of 12.30 kilometres, and another section of the line between Zweilütschinen and Grindelwald, a length of 11·14 kilometres, or a total of 23·44 kilometres. There are diagrams showing cross sections of the formation and retaining-walls, &c., also of three types of passenger carriages, the sectional plan and elevation of a locomotive, a large scale diagram showing the pitch and form of the rack teeth and photo-lithographed views of the stations at Grindelwald and Lauterbrunnen, and of other places on the line. Diagrams are also given showing the details of this railway and, in addition, of the following lines: viz., Rohrschach to Heiden Railway, Ostermundigen Quarry Railway, Brünig Railway, and St. Gallien-Gais Road Tramway, and Neuchâtel, Cortaillod, Boudry Road Tramway.

A comparative Table of particulars as regards gauge, length, inclines, permanent-way, rolling-stock, &c., of this, the Bernese-Oberland, and of five other railways is given. This line, in respect to gauge (1 metre), form of permanent-way, brakes, wagon-frames and some other particulars, is similar to the Brünig-Brienz Railway.

Between Interlaken and Zweilütschinen it is laid as a simple adhesion railway, the steepest grade, about 1 kilometre in length, being 1 in 40, but between that and Grindelwald the character of the valley was such as to necessitate laying the rack-rail for two stretches of about 1·90 kilometres and 1·1 kilometres respectively, the steepest grade being 1 in 8. The type of rack-rail adopted is the Riggenbach. On the length between Zweilütschinen and Lauterbrunnen the rack-rail is laid on two lengths of about 0·9 kilometre and 0·8 kilometre respectively, the steepest grade being 1 in 8·33. In consequence of the nature of the country traversed, great care is requisite to keep the line clear both in winter and summer, and to guard against the effects of avalanches, floods, &c.

Near Wilderswyl the river is crossed by a wrought-iron lattice bridge of 30 metres span. A short distance beyond the junction at Zweilütschinen the line to Lauterbrunnen crosses the main road to Grindelwald and again the river, near which an avalanche track had to be dealt with, necessitating the driving of some thousands of piles and the construction of numerous retaining walls.

The line to Grindelwald, on leaving Zweilütschinen, passes the village of Gündlischwand, where there is a tunnel of 60 metres long, and beyond that the "Mannlichen" avalanche track, which is passed under by an arched way of 27 metres in length, which had to be constructed of unusual strength and cost 2,000 francs per metre; this has since been lengthened at each end by a timbered covered way.

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At Lütschenthal the river is crossed, and from that station an incline laid with rack-rail commences and continues up to Burglauenen, a spot which is so shut in that the sun's rays do not reach it during the four winter months.

From here the line runs through the comparatively flat bed of the valley, until at rather less than a mile from Grindelwald it again rises with a rack-rail incline until close upon its termination.

A Table of altitudes above sea-level is given of various points on the line. Interlaken is at an altitude of 570·30 metres, Lauterbrunnen at 799·30 metres, and Grindelwald 1037·60 metres.

The adhesion rails are of Bessemer steel with fished joints and cross-sleepers of oak, 1·8 metres long × 18 centimetres × 13 centimetres; the normal length of the rails is 9·60 metres, or three times the length of the rack-rails, viz., 3·20 metres. The depth of the adhesion rails is 110 millimetres, the breadth of head 50 millimetres, and of foot 90 millimetres; their weight is 23 kilograms per metre. The fastenings of rail and sleeper comprise a group of one spike and two wood screws, and there are bed plates under the rail at each sleeper. On curves the road is ballasted up flush with rail level.

The rails are inclined inward 1 in 20; on curves of 100 metres radius the super-elevation of the outer rail is 60 millimetres and the gauge is increased by 20 millimetres.

On the rack inclines where on the curve, the speed being low, the elevation of the outer rail and the spread of the gauge is only slight. On the rack-rail portion where the incline is steeper than 1 in 10 there is a concrete backing to the sleepers to prevent creep. The Author remarks that the permanent-way as above described is found to be sufficiently stable but without much margin, as the 28½-ton locomotive with its rigid base of 2·7 metres tends here and there to distort the true line of the road. As regards the rack-rail portion, the most unfavourable conditions are with a descending train, the engine at the head but running backwards, and with air-filled cylinders working much less steadily than on the ascent when in steam, a rolling motion being especially noticeable when the rails are damp. Although wrought-iron or steel sleepers possess many advantages, on account of the ground being as a rule hard frozen for six months in the year, timber sleepers were here adopted to reduce concussion and lessen the number of broken springs.

The rack-rail is here formed by two channel-bars placed back to back, the intervening rack space being 13·5 centimetres. The rack is formed by bolts of 36 millimetres in diameter, these bolts passing through holes in the webs of the channel-bars. The joint-saddle for the rack-rail is formed by two channel-bars each 105 millimetres × 66 millimetres × 9 millimetres and 0·69 metre long, placed 9 millimetres back to back, with an intervening space of 139 millimetres and riveted to a base-plate 490 millimetres wide which rests on the sleeper on each side of the joint; this base-plate is turned down at a right

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angle on the up incline side of the sleeper. The joint-saddle is just long enough, viz., 0·69 metre, to stretch across the sleepers each side of the joint and the intervening space, and supports the rack-rail channel-bars on its top and is bolted to the latter by eight bolts, four on each side. At each of the remaining sleepers there is also a saddle intervening between the under side of the rack-rail channel-bars and the top of the timber cross-sleeper. This saddle is of bent plate, 115 millimetres high, splayed out below and screwed to the sleepers; to its top is bolted the rack-rail angle-bars. The channel-bars and rack-bars are made of Thomas steel. This form of rack-rail has proved satisfactory in working and maintenance.

The carriages illustrated in the Paper are, 1st, a four-axle carriage (a two-axle bogie at each end) for sixty passengers, the length over buffers being 12·37 metres, and weight, empty, 8½ tons; 2nd, a carriage of the same length as the above, but for forty passengers only, the remaining space being for luggage; and, 3rd, a three-axle carriage for forty passengers, 9·28 metres in length (less the buffers). The width of these carriages over all is 2·7 metres.

The locomotives are three-axle, coupled, tender-engines with independent cylinders for the adhesion- and rack-wheels. The length over buffers is 7·17 metres; the wheel-base is 2·7 metres; the maximum steam-pressure 12 kilograms per square centimetre; the weight, empty and in running trim, 23·6 and 28·5 tons respectively. The diameter of the adhesion- and of the rack-wheel cylinders is 320 millimetres, and the stroke of the former is 450 millimetres, and of the latter 400 millimetres. The price of this engine at the factory was 54,500 francs. There are six engines of this type, and another of 15 tons in use since 1893 which cost 27,000 francs. The stations are described.

A Table gives the comparative cost of this and three other adjacent lines and their traffic receipts for 1893.

D. G.

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*The Railway System of the Island of Java.* By A. Snethlage.

(Revue générale des Chemins de fer, June, 1896, p. 329.)

The first Concession for a railway in the island of Java was granted in 1862 for a line from Semarang to Djokja, which was soon followed by another for a line from Batavia to Buitenzorg. A company called the "Dutch-Indian Railway" was founded with the object of constructing and working these lines, which were opened in 1873. So little confidence was shown in the success of the lines that the Government of the Dutch Indies was obliged to guarantee interest of 4½ per cent. during the construction. The Government were soon convinced that private enterprise would not suffice for the construction of a well-designed system of railways, and decided therefore to construct a system themselves. At the end of 1894 the State railways had a length of 677 miles,

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representing a capital of £7,440,000, or £10,846 per mile, which yielded a net profit of 4·70 per cent.

Although several concessions were granted between 1873 and 1893, two lines only, 50 miles in length, were constructed, as well as two steam tramways, 170 miles in length. The regulation of 1893 for the construction and working of steam tramways, giving to companies greater liberty, led to the promotion of several "economical" lines, under the name of steam tramways, which are constructed so that the rolling-stock of the State railways can circulate upon them. These economical railways, of which 201 miles are in course of construction, will cost £4,466 per mile including the rolling-stock. The type of rail adopted is that used on the State railways, weighing 52 lbs. per yard, and having a length of 33·46 feet. The gradients are not steeper than 1 in 200 and the lowest radius for curves is 7½ chains. The locomotives are six-wheel-coupled and weigh 21 tons in service. The regulation allows a train-length of 131 yards (corresponding to a weight of 200 tons), a speed of 15½ miles an hour along the roads, and 25 miles an hour along the other portions. The line can be laid along the roads so long as there remains for vehicular traffic a width of from 14·76 feet to 18 feet, according to the amount of traffic; the road bridges belonging to the Government can also be used when their width is sufficient to have 8·20 feet for vehicles and pedestrians.

At the end of 1894 the railways in Java had a total length of 1073 miles in working order, and about 370 miles were in course of construction. The total receipts in 1894 were £1,063,665, or £1,050 per mile, whilst the net receipts were £598,376, or 5·71 per cent. of the capital cost.

On the main line from Batavia to Soerabaia gradients of 1 in 25 and curves of 7½ chains are met with, but in the eastern part of the island they are not generally greater than 1 in 200, and 25 chains respectively. The gauge for the whole of the system is 3 feet 6 inches, with the exception of the Semerang-Djokja line and its branches, which are laid with a gauge of 4 feet 8½ inches; on a portion of the latter railway three rails are laid on the same sleepers to suit both gauges. The steel rails, weighing 52 lbs. per yard, are laid on wooden sleepers, 6·56 feet long by 8·66 inches by 4·72 inches.

The maximum load for passenger trains on gradients of 1 in 25 is 84 tons (two locomotives), with a speed of 15½ miles an hour, and on gradients of 1 in 40, 160 tons (one locomotive), with a speed of 37 miles an hour. For mixed trains the maximum load on gradients of 1 in 200 is 324 tons (one locomotive), with a speed of 28 miles an hour.

Various types of carriages are used, and details are given of two six-wheeled and two four-wheeled composite carriages belonging to the State railway and the Dutch-Indian railway. The wagons of the different companies are more uniform because all have to travel over the steam tramways.

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Various types of locomotives are used, and the Author gives the following Table of the principal dimensions of one of the lightest and of one of the heaviest locomotives used on the State railways:—

| | Three Axled, Four-wheel-coupled Tank Engine. | Four Axled, Six-wheel-coupled Compound Tank Engine. |
|---|---|---|
| Weight, empty | 11·61 tons | 24·80 tons |
| Interior diameter of boiler | 2·77 feet | 3·77 feet |
| Length of boiler | 6·85 „ | 10·00 „ |
| Number of tubes | 82 | 157 |
| Fire-box surface | 40·00 square feet | 52·64 square feet |
| Heating surface of tubes | 219·81 „ „ | 599·14 „ „ |
| Total heating surface | 259·81 „ „ | 651·78 „ „ |
| Diameter of cylinders | 11·02 inches | 14·96 inches<br>22·83 „ |
| Stroke of piston | 14·96 „ | 20·00 „ |
| Diameter of driving-wheels | 3·86 feet | 3·62 feet |

Detailed statistics are given of the tariffs and traffic, and Tables showing the revenue accounts for the whole of the railways for the year 1894.

A map accompanies the Paper. J. A. T.

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## *The Beyroot-Damascus-Hauran Railway.* By — BLANCHE.

(Revue générale des Chemins de fer, June, 1896, p. 342.)

In 1863 a Concession was granted to a French company to act as carriers between Beyroot and Damascus by means of a carriage-road 69½ miles in length. In 1891 the population of Beyroot had risen from 25,000 in 1863 to 120,000, and that of Damascus from 100,000 to 200,000 in the same period; and the means of transport had become so insufficient that a Concession for a period of ninety-nine years was granted by the Ottoman Government for a railway from Beyroot to Damascus, and a second line from Damascus to Mzerib in Hauran with a capital of £400,000. The 157 miles comprised in these lines form the narrow-gauge portion of the Syrian system, the same company obtaining a Concession in 1893 for normal gauge lines, which will serve Homs, Aleppo and other towns on the Euphrates with several branches, placing them in communication with the sea and with the railway system of Turkey in Europe. The normal gauge lines are guaranteed by the Government; the 157 miles of the Beyroot-Damascus-Hauran Railway are not.

Considerable difficulty was encountered in laying out the line between Beyroot and Damascus, inasmuch as the Lebanon and Anti-Lebanon mountain ranges had to be crossed with lowest altitudes of 4,823 feet and 4,593 feet respectively. A scheme was proposed in 1889 in which the gauge was fixed at 3·28 feet, with a minimum radius of 7½ chains and a maximum gradient of 1 in

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50, but it was found to be so costly that it had to be abandoned. The next scheme suggested was to use the rack system for climbing over the steep slopes of the Lebanon, and eventually the Abt system of rack- and adhesion-rail combined was adopted. The works were commenced at the end of 1892, and the line between Beyroot and Damascus was opened in August, 1895. The extension from Damascus to the Hauran—66 miles in length—was opened in the following year; but no difficulty was experienced on this section, as the region through which it passes is practically a plain. The line between Beyroot and Damascus is 91 miles in length; the maximum gradients for the rack sections are fixed at 1 in 14·28 in the Beyroot to Damascus direction (import traffic), and at 1 in 16·66 in the contrary direction (export traffic). The maximum gradients for the adhesion sections are 1 in 40; 1 in 33·33 is exceptionally attained, but in these cases the minimum radius is not used. In crossing the Lebanon the only curve used, both in the rack and adhesion sections, has a radius of 6 chains; the minimum radius on the rest of the line is 5 chains. With the object of avoiding heavy masonry works in crossing the Lebanon two turnbacks have been laid.

The total quantity of earthwork, including rock excavation, amounted to 1,482,000 cubic yards, or 9·21 cubic yards per lineal yard. There are 811 bridges, culverts, etc., on the line, in addition to four tunnels, having together a total length of 797 yards. The terms of the Concession left the choice of a gauge between 3·44 feet and 4·76 feet to the Company, who adopted the minimum. Vignoles steel rails are used, with steel sleepers on the "Roth and Schueler" system (Visp-Zermatt type). The rails weigh 55·68 lbs. per yard, are $4\frac{19}{32}$ inches in height, with a flange width of $3\frac{31}{32}$ inches. The normal length of rail is 29·53 feet. Hollow soft steel sleepers are used, 6·07 feet in length, weighing 83·33 lbs. each. The total weight of the permanent way (rails, sleepers and fastenings) is 216·93 lbs. per lineal yard.

The rack consists of two plates, $1\frac{1}{32}$ inch in thickness and $4\frac{11}{32}$ inches in height, which are placed $1\frac{19}{32}$ inch apart. The plates are 5·91 feet in length, break joint with each other, and are manufactured of the best Martin-Siemens steel. The teeth have a width at their origin of $2\frac{3}{8}$ inches, the inclination of their sides is 1 in 4, and their depth is $1\frac{31}{32}$ inch.

There are three large passenger- and goods-stations at Beyroot, Maallaka and Damascus, and twenty-one intermediate stations, the average distance between stations being 4 miles. When the line was opened the rolling stock consisted of seven rack locomotives, thirteen adhesion locomotives, one hundred and ten wagons, five covered wagons, and twenty passenger carriages, but in the course of the present year these numbers will be considerably increased.

According to the specification the rack engines were to be built in order to draw a train of 80 tons at a speed of 5·59 miles an hour on the maximum gradient of 1 in 14·29, or a train of 100 tons at the same speed on a gradient of 1 in 16·66. In the



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adhesion sections they were to be able to draw a train of 100 tons on a gradient of 1 in 40, at a speed of 10 miles an hour. The following are the principal dimensions of these engines:—

| | |
|---|---|
| Total heating surface | 1,031 square feet. |
| Direct „ „ | 86 „ „ |
| Grate surface | 17·55 „ „ |
| Number of tubes | 207 |
| Pinion cylinders, diameter | 14·96 inches. |
| „ „ stroke | 17·72 „ |
| Adhesion „ diameter | 14·96 „ |
| „ „ stroke | 19·68 „ |
| Water in boiler | 691 gallons. |
| Volume of steam | 46 cubic feet. |
| Feed-water in tank | 1,100 gallons. |
| Coal in bunkers | 2½ tons. |
| Diameter of coupled wheels | 2·95 feet. |
| „ pinions | 2·25 „ |
| Distance between axles of pinions | 3·05 „ |
| Rigid wheel base | 9·84 „ |
| Total „ „ | 17·22 „ |
| Total length between buffers | 31·02 „ |
| Total width, all projections included | 9·02 „ |
| Weight, empty | 33·56 tons. |
| „ in service | 44·03 „ |

The section from Maallaka to Damascus, 56 miles in length, is worked by adhesion locomotives alone, and these engines, which are of the "Mogul" type, are fully described, and are, like the rack engines, provided with the vacuum brake. All the engines were constructed at Winterthur. The Author gives the calculations on which the principal dimensions of the engines were based.

Ten plates are annexed giving details of the permanent way, locomotives, stations, and longitudinal section, &c.

J. A. T.

## *The Duration of Railway Wagons with Iron Frames.*

By L. Tolmer.

(Revue générale des Chemins de fer, May, 1896, p. 306.)

The Paper refers to a number of tests made by the Author for the Eastern Railway of France in order to determine the probable life of wagons with frames and bodies either partially or wholly of iron. In order to carry out the tests, wagons of the oldest age were chosen, and each piece was weighed after being well scraped to get rid of all rust and paint. The wagons submitted to examination were of four types, as follows:—

(1) Class L, constructed about 1861, with wooden under frame and iron upper frame.

(2) Class H, constructed about 1865, with mixed under frame and wooden upper frame. Class L, constructed about 1865, with mixed under frame and iron upper frame.

(3) Class H, constructed about 1869, with iron under frames

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and upper frames. Class L, constructed about 1875, with iron under frames and upper frames.

(4) Class U, constructed about 1874, entirely of iron, with the exception of the flooring.

A detailed Table is given showing the loss of weight in the various pieces of eight wagons chosen from the above types. The following are briefly the results of the examination.

(1) These wagons, dating from 1861, have had an average length of service of thirty-two years, and it was found that the ironwork had lost 6 per cent. of its original weight, due mostly to oxidation. By repairing and renewing, at a cost of about £1 per wagon, the Author considers that their probable length of service is between thirty and forty years.

(2) These wagons have had a length of service of from twenty-five to thirty years. The probable length of service of the iron soles will be from fifty to sixty years, and by renewing certain portions of the upper frame at a cost of about £1, it will last from thirty-five to forty years; if the upper frame is then renewed at a cost of about £11, the whole wagon would have a life of from fifty to sixty years.

(3) The principal cause of deterioration in these classes was due to the wear of the rivets; 50 per cent. of the latter were found to have lost 15 per cent. of their weight, and had become loose in their holes. The Author is of opinion that this is due to a great extent to hand riveting, and expects a great improvement by the mechanical riveting now used. The probable length of service by taking precautions in riveting is put down at fifty years, and beyond if particular care is taken to prevent the action of rust. The Author found that the paint commenced to be worn off at the end of three years of service, and in order to prevent rust he considers that the wagons should be painted every three years. The cost of this operation, with at least two coats of oxide paint, he estimates at about 14*s*.

(4) It was found that these wagons, at the end of about twenty years, had lost 4 per cent. of their weight in the under frames, 12½ per cent. in the light scantlings forming the upper frame (which, in order to preserve the plates, should be renewed about every ten years), and about 35 per cent. of the rivets were faulty.

The Author states that the examination has particularly shown the difficulty that is encountered in so arranging that the principal pieces forming the wagon shall need repair at the same time. The framework formed of bars of small thickness contributes to the lightness of the wagon, but does not tend to increase its length of service. The later wagons of the Eastern Company have been built therefore with larger scantlings. These precautions being taken, together with hydraulic riveting and painting every three years, the Author considers that a length of service of from fifty to sixty years may be counted upon.

Seven plates accompany the Paper. J. A. T.



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## *Electric Tramway in Paris.* By CH. JACQUIN.

(L'Eclairage Electrique, vol. vii., 1896, p. 222.)

This line is the first permanent one on the Claret-Viulleumier system, and is entirely different from previous electric lines in Paris, which have all been worked by means of accumulators. An experimental line on the same principle was at work for six months at the Lyons Exhibition with satisfactory results.

The route is along the Avenue de la République and the Avenue Gambetta, and, leaving Paris by the Romainville gate, it traverses Les Lilas, and terminates in the centre of Romainville. The line is 4⅔ miles long, rather over 2½ miles being within the city, very little of this portion being level, the gradient reaching 1 in 21·7. There are numerous curves, especially outside the city, some having a radius of 98 feet. Public lighting by arc lamps is carried out by the tramway company along the city portion of their line.

Work was begun in September, 1895, and by the following March the greater part of the mains and track were finished and lighting begun from the station. This last is situated at Les Lilas in the Avenue de Paris, rather less than 1,000 yards from the gate. The works and car-shed are side by side, and are of approximately the same size; there is space for housing fifty cars. The engine-room contains three engines of 200 HP. each, two being in use and one in reserve, and there is space for three more. The engines are horizontal single-cylinder condensing, and each drives, by means of a leather belt, a 140 kilowatt 4-pole dynamo, over-compounded and giving 500 volts. Water is obtained from an open reservoir fed from a well. The boilers are three in number, and are of the semi-tubular type.

Current for the motors is collected by means of brushes, which are fixed beneath the cars and which press on a rail flush with the surface of the ground; the track serves as the return. This rail is divided into sections, each of which is a little shorter than a car; the sections are divided into groups of eighteen, and each group is connected to an automatic apparatus called a "distributor," which is the distinguishing feature of the system. It is somewhat similar in principle to the Baudot telegraph distributor, and serves to successively excite the sections as the car passes over them, those sections not covered by a car being insulated. The distributors are permanently connected to the feeders, which are laid underground. The feeders are connected to the positive-pole of the dynamos, the track to the negative.

At Lyons the conducting-rail was composed of a series of iron bands, about 13 feet long, embedded in bitumen; but the Paris authorities objected to this construction, as horses were likely to slip, and therefore metallic blocks, insulated also with bitumen, were substituted; the blocks were placed 8 feet apart, and were connected together in pairs by an insulated cable 0·012 square inch in section laid a few inches below the surface. This arrangement

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necessitated having collectors over 8 feet long, the actual length being rather under 10 feet in order to enable contact to be made with one section before the last was left. The collector is formed of an iron band pressed down on the ground by springs.

The various sections are connected to the distributors by means of rubber cables, 0·012 square inch in section, run across the line in cast-iron pipes 2½ inches in diameter, and then parallel to the line in the same trench as the feeders. These last are insulated with jute, lead-covered and armoured. There are two feeders: one nearly 3¾ miles long and having a sectional area of 0·46 square inch; the other nearly 1½ miles long and 0·35 square inch in section. The distributors themselves are drum-shaped, and are 15¾ inches diameter and rather under 8 inches thick; they are contained in circular cast-iron boxes fixed in line with the cable trench, which is under the footpath, and precautions are taken to keep out water. A spare distributor is carried by each car and can be substituted for a faulty one in a few minutes.

The cars are rather over 28 feet long, and will seat fifty-six passengers; a compartment for luggage is also provided. They are lighted by means of five lamps placed in series, a second circuit of five being provided as a stand-by. Two motors are provided; they are suspended from the frame by means of springs and are geared to the axles, the speed being reduced to one-fifth. They can be connected either in series or parallel. A screw-brake is provided for emergency use. There are fifteen motor-cars running and five under construction, and some trailers will be added for use during the busy part of the day. The service is a five-minute one.

The street lighting is carried out by means of 10-ampere arc-lamps connected nine in series, and there are fourteen circuits; these are fed from a jute insulated cable, 0·186 square inch in section, laid in the same trench as the tramway cables.

C. H. W.

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## *Combined Electric Light and Tramway Working at Hamburg.*

By MAX MEYER.

(L'Industrie Électrique, 1896, p. 245.)

For some time past the central station belonging to the Hamburg municipality, and situated in the Poststrasse, has been used to provide current for electric lighting and tramway purposes, there being two sets of steam dynamos, each of 600 HP., and two batteries of accumulators, together with three similar sets of generating plant employed for the tramways, and a spare set in reserve of the same size. Nearly a mile distant from this station there has lately been built and equipped a new one having a capacity of 5,000 HP., and this will almost entirely serve from

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the present time to furnish current for the tramways, leaving the other one free for extensions of electric light, which are much required.

The Hamburg electric tramways, it will be remembered, cover a very large area, and have a total length unsurpassed by any other city in Europe; the average number of motor-cars running last winter was 175, besides 60 trailer-cars. The farthest point of the network from the power-house is a little under 7 miles.

The Author gives three Tables showing various figures and statistics relating to the enterprise, both for lighting and traction, and these are both interesting and valuable. At the end of 1895, the total number of glow-lamps connected was 31,861; arc-lamps, 1,342; motors, 130; involving on the lighting circuits alone a total consumption of 2,213,800 watts. In kilowatt-hours, the production for December, 1895, was 695,263; of this the accumulators took 46,695 and returned 40,798—an efficiency of 87·5 per cent. Of the 687,323 kilowatt-hours distributed or put into the mains, the central station took 5,879; private lighting, &c., 187,611; public lighting, 7,404; and the tramways, 385,318, equivalent to 763 watt-hours per mile per train of one motor-car plus an average of one-third of a trailer-car. These totals leave 14·8 per cent. of the energy distributed as being lost in the mains or otherwise unaccounted for. The proportion of lamps burning to those installed reached as much as 48 per cent.

The amount of coal burnt for the same month averaged 2½ lbs. per kilowatt-hour generated, and 3 lbs. per kilowatt-hour actually used, inclusive of coal for lighting up the boilers. English smokeless coal is used of an evaporative capacity equal to 9⅓ lbs. water, and delivered at the works for 16*s.* 7*d.* per ton. The five machines at the Poststrasse station (to which all these figures refer) were in operation during December for 2,367 hours, and in the previous May for 1,108 hours, giving total daily averages of 76·4 and 35·7 hours, or for each machine 15·3 and 7·15 hours respectively. In proportion to the normal loads, viz., 500 HP. each, this gives a load factor of 56 and 30 for these two extreme cases over the whole twenty-four hours.

The expenses for December showed a total of 0·7*d.* per kilowatt-hour useful, coal being responsible for 0·3*d.* of this.

F. B. L.

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## *The Polyphase Electric Street Railway in Lugano.*

(Elektrotechnische Zeitschrift, 1896, p. 193. 7 Figs.)

The Author points out that polyphase currents used for railway work have advantages and disadvantages over direct currents. The chief disadvantage is that at least two overhead wires must be used. These, however, can be made very light, and the supports lighter also. At crossings one wire only is needed for

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use, as the motor, when once started, will work as a single-phase machine. The tendency to sparking on the trolleys is considerably less. The chief advantage, however, of the polyphase system is that current at high potential can be produced at a distance and brought to certain points on the line, and there transformed to a suitable lower potential, thus avoiding the necessity for using heavy mains. The motors have no troublesome commutators, but only slip rings. It has often been thought that polyphase motors have only a feeble torque at starting; this is, however, quite an error, as they can develop more power relatively than direct-current motors, for the latter have far more induction in the iron, and therefore their starting power is diminished. For speed-regulation adjustable resistances are inserted in the armature circuit.

The speed of the motor can be varied from zero to that corresponding to synchronism with the current. The resistance is usually cut out altogether, and then the motor runs at a constant speed, however the load may vary. This quality is extremely useful in mounting and descending gradients. In descending a gradient the motor delivers current into the mains without any alteration of switches, and is therefore automatically retarded, so that its speed cannot exceed a known maximum.

With reference to this the first street-railway on the polyphase system, it may be stated that about the middle of 1894 the firm of Brown, Boveri & Co., of Baden (Switzerland), was asked by the firm of Bucher-Dürrer, of Kerns, to get out a scheme for the Lugano railway, and the matter was settled in February, 1895. The description of the work is as follows:—Mr. Bucher-Dürrer has water-power at Maroggia, 7·44 miles from Lugano, and for several years the town of Lugano has been supplied with electric ter[illegible]ght on the alternate-current system; from this source of power previo[illegible]is now used for the street-railway, for the San Salvatore moun- ınd 35·7 [illegible]n-railway, and for the supply of power to certain mills. It ely. In [illegible]s therefore impossible to use direct current at 500 volts to gives a [illegible]0 volts, and a transforming station would have caused too great ver the [illegible]oss.

At Maroggia is installed a high-pressure horizontal shaft-turbine low of 300 HP. by Messrs. Bell & Co., of Kriens, connected by electric couplings to a 150-HP. three-phase generator. They run at 600 revolutions per minute, and develop 5,000 volts with a frequency of forty periods per second. The armature of the generator is fixed, and only the iron parts of the field-magnets revolve. Contrary to the usual arrangement, the rotating pole-shoes are not opposite each other, but poles at one side are opposite openings at the other. The advantage is that the winding is common to both halves of the armature.

The leads to Lugano consist of three copper wires 0·197 inch in diameter, and there is at present only one transformer station in Lugano, near the centre of the network; other stations will be built later. The pressure is reduced to 400 volts. The total

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length of the line is 5,350 yards, and there are stretches of gradient of 3 per cent., and on three short lengths grades of 6 per cent. The two overhead wires are each 0·236 inch in diameter, and are hung at a distance apart of 9·9 inches. The rail-joints are copper-bonded, and no separate return-wire is used. At present four cars are in use, built by the Herbrandt wagon works, Cologne, Ehrenfeld; each carries twenty-four passengers, and has one motor only, of 20 HP., driving the axle through spur-gearing of 1 : 4 ratio. The speed attained is 9·3 miles per hour.

The Author then gives various details as to the construction of the cars and motors. The working of the line would have affected the telephones, and it has been decided to put in metallic returns for the latter.

E. R. D.

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## *Electric Transportation.* By W. Baxter, Jun.

(The Electrical Engineer, New York, vol. xxi., 1896, p. 389.)

In the eighth article of a series devoted to the consideration of the question, "Can electricity supplant the steam locomotive on trunk railways?" the Author gives the following comparative figures. The reasons on which he justifies the figures assumed as correct are fully set out in this and preceding articles.

Taking a passenger train with a steam locomotive, the weight of a five-car train would be as follows:

| | Tons. |
|---|---|
| Five passenger cars | 162·5 |
| Locomotive | 85 |
| 105 passengers | 6·36 |
| Total weight of train | 253·86 |

The weight of the locomotive is thus 33·4 per cent. of the total weight. With electric motors on the cars, the weight of the same train would be:

| | Tons. |
|---|---|
| Cars | 162·5 |
| Passengers | 6·36 |
| Electric motors | 22·00 |
| Total | 190·86 |

In this case the weight of the motors is only 11·5 per cent. of the total weight and the weight of the complete train is also reduced by some 25 per cent. The saving in driving-power would therefore be about the same percentage. For comparing the cost of fuel, the Author assumes that, in an electric station, the consumption of coal would be 2 lbs. per HP. hour, and that, with an efficiency of distribution of 60 per cent., gives 3·33 lbs. per HP. hour delivered to the track.

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He then considers from figures obtained from locomotive practice that the average of 6 lbs. of coal for a freight engine, and 4 lbs. for a passenger engine per HP. hour, is a fair figure to compare with the above. The electric station has also the great advantage of being able to use a low grade and cheap coal, giving an estimated saving of 33 per cent. in the cost of a given weight of coal.

From these figures the Author concludes that the HP. delivered on the track costs three times as much by steam as by electricity for freight work, and twice as much for passenger service. Multiplying these figures by the relative percentages of the power required in both cases to haul given loads, he finds that the cost of coal consumed to move a given load by electricity is about 31 per cent. for freight, and 37 per cent. for passenger work, of what it costs by steam.

R. W. W.

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*Experiments on Boilers and Engines in Alsace with Superheated and Saturated Steam.* By — WALTHER-MEUNIER.

(Bulletin de la Société Industrielle de Mulhouse, April-May, 1896, p. 154.)

Mr. Walther Meunier describes the working of various boilers in Alsace during the year 1895. In one boiler plant the unsatisfactory results obtained were traced to bad stoking and a poor quality of coal. The percentage of $CO_2$ was only 5·3, and of oxygen, in excess of that needed for combustion, 13·2. With more careful stoking and better working conditions the percentage of $CO_2$ was raised to 9·67, of oxygen (in excess), reduced to 7·23, and the boiler efficiency thus increased 35 per cent.

A Frikart compound engine was tested with and without superheating. The diameter of the small cylinder was 27½ inches, of the large 43¼ inches, stroke 6 feet 6 inches, number of revolutions 64¼ per minute. The fuel used was clean Ruhr coal. Three different degrees of superheating were employed. The total power developed varied from 755 I.HP. to 776 I.HP. and the mean steam pressure was 5·7 atmospheres. The steam was first heated to 222° C., or 42° of superheat, and the economy obtained, as compared with saturated steam, was 10·5 per cent. of feed water, and 8 per cent. of coal. The temperature was then raised to 264° C., or 84° superheat, with 14·3 per cent. economy of feed water, and 14·4 per cent. of coal. Lastly, it was superheated 100° and raised to a temperature of 284° C.; economy produced 19·3 per cent. feed water, and 20 per cent. coal. The loss of heat in the steam-pipe varied from 17° C., with the lowest, to 21½° C. with the highest superheating. When good coal was used, the temperature rose to 400° C., so high, in fact, that some of the superheating tubes had to be blocked out. The tests show that the consumption of

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steam in the engine diminished as the degree of superheat increased. It was 16·5 lbs. per I.HP. hour with saturated steam, and fell to 13·2 lbs. with steam superheated 100° C.

Another series of experiments were made with saturated steam on a compound engine of Messrs. Dujardin at Lille. The boilers were semi-tubular with a Green economiser, and four were in use during the trial. The diameter of the cylinders was 2 feet 5 inches and 4 feet 5 inches respectively, and stroke 5 feet 7 inches. The coal used was dry-washed Châtelineau, boiler pressure 6½ atmospheres, number of revolutions 59½ per minute, mean total I.HP. 695. The weight of steam per hour per I.HP. was 14·3 lbs. including the steam in the jackets, and of coal 1·56 lb. per I.HP. hour. The evaporation of water per hour per square foot of heating surface was 1·94 lb.

Another compound engine of the Sulzer type, made by Messrs. Tosi of Legnano in Italy, was tested. The boiler was semi-tubular, diameter of the high-pressure cylinder 21·6 inches, of the low-pressure cylinder 33·4 inches, stroke 3 feet 5 inches. The coal used was Amercœur, washed. The boiler pressure in the first trial under ordinary working conditions was 5·8 atmospheres, in the second trial 6·8 atmospheres, number of revolutions 75. The mean power developed during the first test was 151 HP., during the second 194 HP. The consumption of steam per I.HP. hour, including the jacket-water, was 16 lbs. in the first and 14 lbs. in the second trial, and of coal 2·2 lbs. and 1·9 lb. respectively.

B. D.

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*A Self-cooling Condenser.* By Louis R. Alberger.

(The Electrical World, New York, vol. xxvii., 1896, p. 713.)

All condensing apparatus—whether jet or surface—depends of course for its successful operation upon an adequate supply of cold water. In many cases where the engine-house is situated alongside or near a large river, canal, pond, or the sea, and where there is accordingly a considerable mass of water to be drawn upon, the injection water is simply pumped up into the condenser and returned after doing its duty, the amount of water in the reservoir being large enough under ordinary circumstances to secure its cooling from atmospheric evaporation. When the supply of water is limited, however, and perhaps has to be paid for, as in the case of many large factories and works in towns and cities, the problem of quickly cooling the condensation-water becomes more serious, and usually a jet condenser is then employed, the mixed water and condensed steam being perhaps partly drawn upon (after filtration) for boiler-feed purposes, passing through an economiser on its way to the boilers. It is, however, essential even under such conditions, to cool very quickly the greater part of the

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condensing water in order that it may be used again without taking up valuable space for water storage, and many appliances are employed for this purpose, most of them involving the use of a high tower of iron plates, to the top of which the water is pumped from the condensers; it then flows down, falling over loosely packed material with which the inside of the tower is filled, and meeting a current of cold air forced upwards within the tower by means of a rotary fan or blower.

The Author describes such an arrangement, the chief novelties of which appear to be two in number; the first consists of a Barker's mill device for spreading the discharge at the top of the tower, and the second, of a filling for the tower composed of ordinary drain-pipes or cylindrical tiles built up one above the other, so as to break up the openings and present a large surface for cooling the water.

F. B. L.

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*The Dynamic Effects in Boiler Explosions.* By P. Dubiau.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1896, p. 18)

The Author states that the destructive effects of boiler explosions have led many engineers to propound theories to explain what they think to be mysterious phenomena. These theories include references to superheating of water, the absence of air in the liquid mass, electric effects, etc. The Author, with the help of his colleague Mr. Vinçotte, has investigated a large number of cases of boiler explosion. As a result of the knowledge so gained they conclude that (*a*) explosions are due either to the natural deterioration of the boilers or to faults in construction. (*b*) The steam-pressure is never increased in a boiler otherwise than by the natural and progressive action of the furnace, and that there is no known phenomenon to cause a sudden increase of pressure. (*c*) The action attributed to a superheating of the water or to a spheroidical state is not confirmed by any practical experience. (*d*) The explosion of a boiler is not an instantaneous effect. The rent commences at the point of least resistance and spreads to the neighbouring parts only if the shell is not able to withstand both the pressure which the failure of the plate puts on them and the blow due to the movements of the sides of this rent in taking up a new position of equilibrium. (*e*) The number and directions of the rents depend on the resistance of the parts around this first fault. Even a large tear does not produce an explosion if the surrounding parts are sufficiently strong. (*f*) In an explosion the pressure of steam does not fall immediately a fracture occurs. On the other hand, with a small fracture, the pressure remains practically constant till all the water has left the boiler. (*g*) The destructive nature of explosion increases with the increase in the

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orifices caused by the fractures in the boiler shell made before the water has escaped. (*h*) There is no connection between boiler explosions and what is known as the spheroidal state. The Author then explains the difficulty of determining from the fragments of the boiler shell after an explosion which was the point of the first fracture. The numerous cases of explosions differ so much in their destructive effects that at first it seems impossible to account for the variation. Admitting that the dynamic effects ought to be in proportion to the pressure and to the volume of water in the boiler, it is found that this is not a reliable means of comparison, as some boilers of relatively small capacities have caused most disastrous explosions. The Author investigates what happens when the first fracture occurs and the effects of the position and magnitude of this first fracture. He shows what energy will be developed in each case and arrives at the following conclusions :—

(1) Great dynamic effects are the result of an explosion in the interior of the boiler. Such explosions are characterised by the fractures often taking the line of greatest resistance and give fragments somewhat like broken pottery.

(2) The interior explosion is caused by the energy given off when the surface of the heated water is suddenly exposed to a diminished pressure such as that of the atmosphere.

(3) The instantaneous dynamic effects depend on the magnitude of the surface of water so exposed.

(4) With equal surfaces exposed the energy developed will be proportional to the volume in the boiler.

(5) Fractures in the lower parts of the boiler and below the water-line are only dangerous when there is an external resistance presented at the point of fracture.

(6) Fractures in the steam spaces are the most dangerous. This is due to the fact that steam issues from an orifice much more quickly than water, and hence a more sudden diminution of pressure results.

The Author illustrates and describes a series of cases where boilers have exploded and shows that the recorded facts agree with the above. He regrets that the public records of explosions are not more reliable and explicit. The last case described is that of a boiler explosion at Aubagne in 1877, of which full details are recorded. The boiler in question was of rather an unusual type, having two small longitudinal shells in the main flue connected by end tubes to a larger drum above. This large drum consisted of five rings and two hemispherical ends. The first fracture occurred in one of the end rings in the steam space. An explosion then took place in the upper drum which detached the end consisting of four rings from the rest of the boiler and threw it out of the boiler-house. It fell in the street some 192 yards away. Then it exploded again. The hemispherical end with a ring was detached and projected 23 yards further, lodging in a tree. The two small shells left in their seating after the first

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rupture were both exploded owing to the water surface being exposed to atmospheric pressure.

The Author shows how these facts accord with the general principle he has laid down. The article is illustrated by fifteen blocks.

R. W. W.

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## *Experiments on the Combustion of Lighting-Gas in Gas-Engines.*

By Dr. FRITZ HABER and HERR A. WEBER.

(Habilitationschrift für Chemie Technische Hochschule zu Karlsruhe, Nov. 1895.)

The combustion of lighting-gas in an engine has been treated by Dr. Slaby in his experiments on gas motors. He assumes that all the heat in the gas is evolved during combustion, and this is correct for the rich mixtures he employed. But if the charge contains 29 per cent. of methane, and the proportion of gas to air is 1 to 6, the percentage of methane will be $\frac{29}{7} = 4 \cdot 1$, the unburnt proportion will be 15 to 44 per cent., and only 80 to 90 per cent. of the heat present will be actually developed during combustion. A comparison of the results obtained by analysis of the exhaust gases, with the theoretical analysis deduced from the composition of lighting-gas, shows that there is less oxygen in the former, the proportion being 4·8 per cent. in theory, and 3·3 per cent. in practice. Dr. Slaby attributes this difference to the combustion of the lubricating oil, but this view is contested by the Author. Both lighting-gas and lubricating oil yield $CO_2$ and $H_2O$ (water vapour) as products. The rule in the case of gases of combustion is, that for equal quantities of carbonic acid the percentage of oxygen is greater, the greater the ratio of carbon to hydrogen, in excess of a certain fixed quantity. This is graphically shown by Bunte, who proves that for an equal percentage of $CO_2$, the quantity of oxygen increases, the more lubricating oil is burnt. It is this difference between the actual and theoretical quantities of oxygen in the exhaust gases which the Author proceeds to discuss.

In making experiments on the products of combustion, analysis by weight is the more accurate method. The water vapour, or steam and $CO_2$, are first separated, the combustible elements then burnt off, and the $CO_2$ and $H_2O$ evolved during the process withdrawn. The amount of acetylene is determined by amalgamation with silver. With the steam certain fine fluid particles, always present in gas-engine products, are also separated; these are caused by the emulsion of the lubricating oil into the stream of gas. The separation is effected by carrying the gases of combustion through a calcium chloride tube, then through an absorption coil filled with concentrated sulphuric acid, and, lastly,

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through tubes containing phosphorus pentoxide. Thus freed from moisture the gases are next led through a Geissler potassium apparatus, and a U-tube with soda lime to absorb the $CO_2$. All these are placed near the vessels in which the experimental combustion takes place. From the weight of the carbonic acid, and the known composition of the lighting gas, the weight of steam is deduced. The weights of carbonic acid before combustion and after passing through the absorption tubes are compared, and the efficiency of the experimental combustion determined. The proportional weights of carbon and hydrogen in methane are also calculated, and from them the ratio of free hydrogen and CO. All instruments were tested for leakage. After separating the $CO_2$ and water vapour, there is a small residuum of methane in the products, to be treated by burning. This was carried out in a glass tube filled with spongy platinum, and heated in a furnace till it began to melt. As the melting point of the tube was 750° C., and methane burns with platinum at 404° C. to 414° C., complete combustion was ensured.

The next point was to separate the hydrogen from the carbonic oxide by fractional combustion. The Author is of opinion that this cannot be done over platinum or palladium, as the hydrogen lowers the temperature of the carbonic oxide, although the latter raises the temperature of combustion of the hydrogen. When mixed, they remain unaffected at temperatures at which, under other conditions, the hydrogen would oxidize by contact with the platinum and palladium, and combustion is always gradual. With mixtures of carburetted hydrogen, H, and CO, it is impossible to burn off the gases successively, and those remaining unchanged after the combustion of the H and CO—chiefly methane —must be separated.

In making the experiments the gases were first burnt in a U-tube, the lower part of which was filled with spongy platinum, and plunged in a glass vessel containing water, oil, or sodium nitrate, according to the temperature required. Aniline, chinoline, and sulphur were also used to produce given temperatures. The water generated during combustion was carefully determined with prussiate of potash and iron ammonia alum, and to ensure accuracy combustion was repeated. CO and H, together or separate, were mixed with moist or dry air in varying proportions, to determine the temperature at which oxidation took place. The platinum was then replaced by a U-tube of palladium wire, and, lastly, coils of palladium wire inside a spiral glass tube were employed, and found to give more complete combustion, because the gases were brought in contact with a larger heating surface. The final preliminary experiments were as follows:—0·88 per cent. hydrogen and 0·97 per cent. carbonic oxide were passed dry through a palladium coil, then through absorption tubes to separate the water vapour and $CO_2$, and, lastly, burnt in tubes lined with spongy platinum brought to a red heat. The proportions of $CO_2$ and water vapour were found to correspond with the original

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volumes of CO and H. To prove from these trials the presence of CO in products of combustion from a gas-engine, it was necessary to show that other chemical elements did not affect the hydrogen in the same manner and cause it to burn at higher temperatures than when unmixed. It is known that methane does not hinder the combustion of hydrogen, and experiments prove that ethylene has the same negative effect. As the quantities of CO and H remaining unburnt are very small in proportion to the quantities already burnt, they may however be neglected.

After these preliminary trials, the Author proceeded to test the composition of the products of combustion from two Otto engines while running. The first was a 4-HP. motor of the old type, with slide valve and flame ignition; the governor acted by wholly cutting off the supply of gas. The second was a modern 2-HP. engine with lift valves and tube ignition, in which the speed was regulated by diminishing the amount of gas. In the slide-valve engine the diameter of cylinder was 6·7 inches, and stroke 13·4 inches; maximum power 4·84 I.HP., and 3·96 B.HP. It was tested first while running regularly, and then by opening the gas-admission valve at varying intervals during the different cycles of revolution, the engine running always at the same speed. This is called a 16-cycle by the Author, because the engine only returned to normal working conditions after 16 revolutions. The 2-HP. valve engine had a cylinder diameter of 5·5 inches, and 8·2 inches stroke. It was worked at full and less power, and the gas-cock so adjusted that during one 4-cycle a rich mixture was admitted to the cylinder, and during the next a poor mixture. The engine was run on the brake by coupling it to a shunt-wound dynamo; at full power it gave 1,200 watts, which fell to 1,000. During the experiments the engine was not lubricated. The gases of combustion were drawn off through a cock in the exhaust pipe connected to a bag of 35 litres volume, and the speed of the water was measured, as it ran out from the bag, and was replaced by the gases. With exhaust products rich in $CO_2$ the bag was two-thirds filled, the temperature, weight, and pressure determined, and pure air then admitted. With exhaust products poor in $CO_2$, such as were obtained when the engine was running at half power, the bag was wholly filled with gas. The proportion of $CO_2$ in gases thus collected diminishes slowly, because it dissolves in the water more rapidly than CO, H, and $CH_4$. Therefore the quantity by weight of the latter appears larger, compared to that of the $CO_2$, the proportion of which is approximately four-fifths of the total volume of the gases. The exact composition of the exhaust gases is not easily known, because they are not homogeneous, and this is probably the reason of the deficiency of oxygen in Dr. Slaby's analysis of gases.

From these experiments it was found that in both engines, when working at full power, there were only traces of combustible gases in the products, but when working at half power considerable quantities of unburnt residuum were given off. This cannot be

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explained by imperfect combustion of the lubricant. In a 10-litre sample of the exhaust gases, 0·0082 gram of $CO_2$, and 0·0086 gram of $H_2O$ were found at full, and 0·0284 gram $CO_2$, and 0·0245 gram of $H_2O$ at half power. The quantity of combustible gases generated by the combustion of the lubricating oil probably increases with the power developed, because the larger the charge in the cylinder, the higher the temperature. The volume of permanent gases, carbonic acid and nitrogen, is less at full than at half power, because the charge contracts 25 per cent. by combustion, and thus the volume of the products may be taken as a test of more or less perfect combustion. The atomic proportion of carbon to hydrogen was about 1 to 4 in both engines, showing the presence of methane and hydrogen. To prevent miss-fires, and the passage of unburnt gas through the cylinder, the admissions and ignitions were registered electrically. Contact was made with the lever of the gas-admission valve and an indicator pencil, which was thrown up at each explosion. The hydrogen was separated from the gases of combustion by Philip's method already described. The presence of CO was detected by placing a live mouse in a bottle, through which the products previously freed from $CO_2$ were led. The mouse was poisoned, and CO was traced in its blood by spectral analysis.

The products from the lift valve-engine were treated in two experiments by fractional combustion, as already described. Allowing for contraction in the volume, the proportions in the exhaust gases of this engine were 0·105 per cent. of $CH_4$, 0·128 per cent. of CO, and 0·104 per cent. of H, or nearly equal quantities of these three gases. To calculate the loss of heat caused by the escape of the combustible residuum in the products, the heating value of the Karlsruhe gas was determined in a Junker's calorimeter, and found to be 583 B.T.U. per cubic foot. Two explosion tests showed that this gas produced 55 litres of $CO_2$ for every 100 litres of the gas, and this proportion gave a loss in heating value in the unburnt residuum of 3·4 per cent. to 4·5 per cent., due to insufficient development of carbonic acid. The proportion by volume of carbonic acid in the exhaust gases with complete combustion would be 16·7 per cent. All these values are shown in Tables, and may be illustrated by Bunte's graphic method.

Three experiments with fractional combustion were made on the exhaust products of the slide-valve engine. The temperature of the cylinder-walls was measured with a thermometer. A hollow in the cylinder-jacket, close to the discharge-pipe, was filled with oil, into which the thermometer was plunged. The proportion of carbon to hydrogen was practically the same as in the lift valve-engine. The per cent. of $CH_4$ was 0·092; of hydrogen, 0·085; and of carbonic oxide, 0·058, or considerably less than in the valve-engine. The loss in heat value due to insufficient production of $CO_2$ was 4·8 per cent. to 5·1 per cent. In this 16-cycle motor it is only the first explosion after two miss-

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fires which is weak and combustion imperfect; in the succeeding explosion complete combustion ought to take place. Thus the quantity of combustible products from the first explosion must be larger than usual, as it is diluted by the products from the last explosion, and the exhaust from two miss-fires.

The Author draws the following conclusions:—Both engines showed perfect combustion at full power, but less perfect combustion, with CO, H, and $CH_4$ in the products, at half power. The lubricating oil plays a small part in the phenomenon of combustion, and the temperature of the jacket-water does not influence it. The explosive mixture is ignited, and burns in a few hundredths of a second. Therefore a low cylinder temperature cannot affect it, because, the gaseous mixture being violently agitated when explosion occurs, and no stratification being possible, it is at the same temperature throughout, corresponding to the inner wall surface. If an explosive mixture is diluted to the limit of inflammability, the temperature of combustion will be low, and combustion itself imperfect, because the flame penetrates and heats the particles for so short a time that they do not all attain the temperature of explosion. If the flame spreads so slowly that combustion can be followed with the eye, it is imperfect. Were the mixture in a gas-engine uniform, the progress of the flame would be so slow that the engine would not work at all. As Dr. Slaby has shown, the explosions in practice are short and sharp, because the mixture in the cylinder is not uniform, but is composed of strong, weak, and non-explosive particles. The poorer the mixture, the more it will contain of the latter. It is these which yield a combustible residuum, probably produced in the following way:—The suction-stroke begins when the compression-space is full of the exhaust products. The latter are drawn back into the volume described by the piston, while the admission-valves successively rise, and layers of gas and air are formed behind the piston. The strata, consisting of exhaust products, air, and explosive mixture, are churned up during the compression-stroke, but a strong explosive mixture remains near the ignition-channel, and a weak mixture next the piston surface. The less rich the mixture of gas and air, the further removed from the piston surface is the limit of violent explosion, and the thicker the weak explosive, or non-explosive, layer. Particles of lighting-gas at high pressure and speed may possibly penetrate this layer, and thus escape ignition, and produce methane and hydrogen in the exhaust. But the presence of carbonic oxide points to more complicated phenomena.

The combustible residuum in the exhaust of the lift-valve engine was probably produced by the smaller quantity of the charge admitted; it is not so easy to understand the cause of the imperfect combustion in the slide-valve engine, except from the weakness of the first explosion after the miss-fires, as shown by the indicator diagrams. In the valve-engine, when running at half power with the cook full open, the first explosion of each series also



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often missed fire. Both engines, in fact, showed the presence of combustible gases in the exhaust products, when the explosions were less violent, the volume of the charge being intentionally reduced in one motor, and the other arranged to give miss-fire cycles. The escape of combustible products in the exhaust is therefore a phenomenon which accompanies weak explosions.

The Paper is accompanied by Tables and indicator diagrams.

B. D.

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*Power Transmission by Compressed Air, Nevada County, California.* By A. DE WINT FOOTE, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, May, 1896, p. 286.)

Compressed air was fixed upon, in preference to other methods of transmitting power, on account of the ease of ensuring the work against stoppage by having in reserve a set of steam-boilers ready for firing, as all the air-motors could be readily converted into steam-motors.

The water supply is obtained from the South Yuba Water Company's canal, Nevada County, California, and is conveyed to the power-house of the Empire Mining Company's works, 2½ miles, in a 22-inch riveted iron pipe continued 1¼ mile by a 20-inch steel pipe, working under a head which increases up to 775 feet at the power-house. Here the water impinges through a nozzle on a Pelton water-wheel, 18 feet 6 inches diameter, running at 110 revolutions per minute and developing 283 HP. It works on a 10 inch shaft, and drives directly a compound air-compressor, with initial cylinders of 18 inches, and second cylinders 10 inches diameter, and a stroke of 24 inches. A 6-inch lap-welded iron pipe conveys the air at 90 lbs. pressure to the shaft, 800 feet distant, and 125 feet higher, where it is used to work a 100-HP. hoisting engine, a 75-HP. pump, besides drills, etc. The pipe-line is laid for the most part along a country road, following its undulations. The trench was dug by ploughs and scrapers, except where stony, and the joint-holes by hand. The pipes were rolled into the trench in lengths and riveted together by hand in place. The leaks that appeared were caulked with the pressure in the pipes, care being taken not to strike heavy blows. It was found that owing to the pressure being so high a small leakage very soon wore a hole through the pipe with the aid of sand present.

The Pelton wheel would have been better if of larger diameter, as this would have enabled the speed of the compressors to be reduced. It is regulated by a float valve actuated by a ball governor. The compressors are arranged to run at ¼, ½ or ¾ full power, for which speeds the wheel has an efficiency of 90 per cent., separate nozzles being provided for each speed.

The air after being compressed in the first cylinders circulates through forty-nine copper tubes, 1 inch diameter, between and

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around which the water passes on its way to the wheel; by this means the temperature of the air is reduced from 200° F. on leaving the first cylinder to 60° F. on entering the second cylinder. The compressed air is delivered into receivers at the shaft and reheated before being used to drive the machinery there.

The efficiency of the whole plant, *i.e.*, the ratio of the work done at the shaft to the theoretical water-power, is 62 per cent.

A. W. B.

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*Structural Steel Fly-Wheels.* By THOMAS E. MURRAY.

(The Electrical World, New York, vol. xxvii., 1896, p. 680.)

The somewhat too frequent bursting of cast-iron fly-wheels of heavy type and large diameter, owing to the increased speeds that are recklessly common, led the Author to devise a structural fly-wheel of open-hearth steel to replace a broken one of cast-iron.

This built-up wheel consists practically of three parts—the hub, the web, and the rim. The hub is formed upon a cast-iron spider or separator 23 inches long and 48 inches diameter, to which are bolted twenty steel disks, six of 36 inches diameter, and fourteen of 48 inches diameter, all in $\frac{3}{4}$-inch metal; the disks are arranged four and four inside the web plates, six and six outside, being eventually secured by thirty-two steel bolts in two rings of sixteen each. The webs are dished, being 2 inches apart at rim and 29 inches at the hub, 19 feet $6\frac{3}{4}$ inches diameter, each composed of two layers of $\frac{1}{4}$-inch plate, and each layer having sixteen sections, making sixty-four plates in all. Thirty-two 5-inch by $\frac{3}{4}$-inch steel bars are riveted over the plate joints, being bent outwards at the rim to form angle-bars for attachment to the rim-plates; and segments of 6-inch by 6-inch by $\frac{1}{2}$-inch angle-bar are riveted round the disk web-plates on each side for a similar purpose. The plates are drilled so as to break joint; the rivet-holes are 3 inches on centres and staggered. In building up the wheel all riveting was done from the outside, with one man inside holding on and taking the hot rivets through a man-hole left for the purpose. For the rim, eight 32-inch by $\frac{1}{2}$-inch plates form the base, to which are riveted the angle-bars and joint-bars, followed by a layer of 40-inch by $\frac{5}{8}$-inch plates, and two of 50 inches by $\frac{5}{8}$ inch, the last forming the belt-surface. The total weight of this wheel is 29 tons, approximately, distributed thus: rim, 16 tons; disk-web, $8\frac{1}{2}$ tons; hub, $4\frac{1}{2}$ tons. The factor of safety is estimated at nearly 26, assuming that the weakest part of the wheel lies in the outer layer of rim-plates, which must obviously give way before the remaining parts.

F. B. L.

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## *The French System of Screw Threads.* By PAUL AUBRY.

(La Revue Technique, 1896, p. 194.)

The system of screw threads proposed in 1894 by the Société d'Encouragement pour l'Industrie Nationale has been adopted by the Railway Companies and by the Navy; its universal adoption is therefore only a matter of time. It became necessary to prepare standard screws and nuts. There is not very much difficulty in measuring and verifying the various portions of the surfaces of a male screw, but the corresponding surfaces of a nut being practically inaccessible the difficulties are very much greater. The verification of nuts is done by means of a screw, but to verify the theoretical nut it is necessary to have a screw which shall be smaller than the theoretical screw by a quantity sufficient to allow the one to move on the other. This quantity depends on the form, the dimensions and the state of the surfaces. For example, a cylinder 6 millimetres in diameter, which can only be driven hard into a hole, will pass freely into the hole if its diameter be diminished by 2 microns. With a cylinder 60 millimetres in diameter, the corresponding difference may be 5 microns or 6 microns.

Let the surface of the standard male screw be made exactly to the theoretical profile, and let that of the standard nut approach it as nearly as possible consistent with practical conditions, the necessary play between the screw and the nut being reduced to a minimum. Then denoting the sizes of the standard screw and nut respectively by E and V

$$E = V + e,$$

$e$ being the play.

For screws and nuts made to fit the primary gauges

$$V' = E - \alpha$$
$$E' = V + \beta$$

$\alpha$ being the play between the standard nut and the secondary screw, $\beta$ the play between the standard screw and secondary nut. Consequently,

$$E' = V' - e + \beta + \alpha$$

—that is, the secondary nut will mount the secondary screw with a play

$$\alpha + \beta - e;$$

from which it follows that the secondary screw and nut will fit each other closer than if they were made to primary gauges both made to the theoretical profile.

Messrs. Bariquand et Marre have made standard screws, nuts and gauges, taking care to ensure accuracy in the four elements of a screw thread, the outside diameter of a screw, the pitch, the

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diameter at the bottom of the thread, and the shape of the sides of the thread.

In making standard screws of hardened steel, the final grinding presents some difficulty. Projecting angles can be finished without difficulty, but a re-entrant angle cannot owing to the wearing away of the angle of the tool. Thus the corners at the bottom of a male screw thread are slightly rounded, while those at the summit may be quite sharp. The sharp corner of a nut will correspond to the rounded corner of the screw and *vice versâ*. The Railway Companies have determined to overcome this difficulty by diminishing the height of the projecting thread.

The Paper is accompanied by ten figures of illustrations.

A. S.

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## *The Sinking of No. III Pit, Rheinpreussen Colliery.*

By A. Lücke.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1896, p. 156.)

The Rheinpreussen Colliery at Homberg, situated on the western extension of the Westphalian Coalfield on the left bank of the Rhine, is remarkable for the difficulties that have been encountered in carrying the pits through the quaternary and tertiary strata overlying the coal measures which range in thickness from 300 feet to 450 feet, the amount increasing in a northerly direction, while the chalk met with on the opposite side of the river is entirely wanting. As these covering strata are largely made up of incoherent materials, boulder drift, gravels and quicksands, the method of boring has necessarily been adopted in preference to sinking by hand. The first pit started with a diameter of 25 feet, but, reduced by various accidents to $8\frac{3}{4}$ feet, when finished, required twenty years for its completion; while the second, although begun with $32\frac{1}{2}$ feet, gave only $13\frac{1}{8}$ feet clear inside when the hard ground was reached after seven years' work, the axis of the tubbing being $4\frac{1}{8}$ feet out of the perpendicular. With such small pits it was difficult to maintain a very large output, as, in addition to the drawing cages, space is required for three surface and one underground pumping engine, as well as the pipes carrying steam from the surface to the fan engine underground; and a third pit was therefore undertaken at a point about 1,200 yards distant from No. II, where a total thickness of 370 feet of water-bearing sands and gravels was found to rest upon a bed of strong sandstone in the coal measures below, the same method as that previously used, namely, boring under water within a water-tight cylinder forced down by pressure from above, being adopted.

The operations commenced on the 1st of December, 1891, with the sinking of a cylinder as a foundation for the boring frame and machinery. This is 40 feet 4 inches outside and 31 feet 2 inches

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inside diameter, built of hard burnt bricks set in cement mortar, with twenty-four vertical tie-rods of 1·6 inch round iron arranged at regular intervals around the circumference, and further strengthened by iron rings 4 inches broad and 1·6 inch thick placed at vertical intervals 39 inches apart. The foot of the cylinder is a 12-inch ring of beechwood shod with iron, and the outer surface is sheathed with smooth planks of the same wood to enable it to sink easily. The material enclosed was removed by hand down to a depth of 16 feet, after which a drag borer worked by a portable engine was used. When the required depth (52½ feet) was reached at the end of May, 1892, the shaft was filled up to the water-level, about half way up to the surface, and allowed to stand during the erection of the deep-boring machinery, which included a 50-ton steam-capstan, an engine for turning the boring rods, three boilers, each of 1,000 square feet heating surface, to work at 120 lbs. pressure, and an electric-lighting plant of two arc and fifty glow-lamps. The boring plant was exactly similar to that used on former occasions and has been fully described before.[1]

In the second stage of the work a brick coffering, strengthened with iron and sheathed with wood, generally similar in construction to the first but of smaller dimensions, 27½ feet outside and 21⅛ feet inside diameter, was used with a cutting shoe of cast iron, put together in eight segments, with a wood backing 2 feet thick. This was sunk in about five months to a depth of 134½ feet, the ground being excavated by dredging down to 69 feet, part of it being through drift containing boulders up to 3 feet in diameter, but below that level the rotatory sack borer was employed.

In the beginning of 1893 a sudden influx of sand and clay into the cylinder occurred, filling it nearly half way up to the surface. This was attended with considerable movement in the ground, causing subsidence of the surface and forcing the two cylinders and the head-gear above about 32 inches out of the perpendicular. The excavation was cleared out by the use of a grab dredger to within 16 feet of the bottom; but as the deviation of the cylinder from the vertical was too great to allow the sinking to be continued of the same size, it became necessary to adopt a reduced section with a cast-iron lining. The pit was therefore plugged with a mass of concrete 25 feet thick, deposited by kibbles with self-acting drop bottoms, and allowed to remain three months to harden; but as it was subsequently found impossible to lower the water by pumping, it became evident that the lining had suffered by the movement of the ground. An investigation made by the officers of the mine, with the assistance of diving apparatus and glow-lamps of fifty-candle power, showed, in several places between 25 feet and 65 feet down, numerous fissures in the wall, both horizontal and vertical, and from 4 inches to 28

[1] Zeitschrift für das Berg-, Hütten und Salinen-Wesen, vols. xl., xvii., xx., xxiii. and xxvii.

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inches wide. The very difficult work of stopping these cracks was undertaken by the same divers, who, standing on a platform suspended from a windlass at the surface, cleared out the fissures and plugged the larger ones with bricks, alternating with layers of dry cement and sand, the latter being packed in linen bags which were afterwards cut by a pointed hammer to allow the materials to mix. The space at the back was then, by means of a 2-inch india-rubber pipe, filled with liquid concrete supplied from the surface through a 4-inch tube; the smaller fissures were closed with wooden wedges. These operations required a total of seventy-six hours' work under water, and it is to the skill with which they were carried out that the saving of the work is principally due.

To continue the sinking a cast-iron tubbing 17 feet diameter inside, built upon a cast steel base ring with cutting edges, was adopted, the column being continuously forced down by a series of twenty hydraulic presses arranged regularly round the top and giving a maximum total pressure of 2,000 tons. These presses bore against a heavy cast-iron ring tied by twelve rods of best wrought-iron 4 inches square to a cast-iron ring of square section built into the brick shaft near the bottom, so that the whole weight of the latter became effective as resistance to the thrust. The brickwork having, by cutting on one side and building on the other, been brought exactly to the size of the outside of the tubbing (18 feet 4½ inches), when the column was built up, the sinking was resumed after fifteen months intermission in March, 1894. The shaft having been filled to the natural water-level, the concrete plug was first shattered by a heavy free-falling tool, the debris being removed by a grab dredger, after which the sack borer was substituted, the pressure being steadily maintained during the boring and increased progressively with the resistance. In August, 1894, when the tubbing was down to 262½ feet, the four-armed boring tool (13⅛ feet with a guide of $16\frac{9}{10}$ feet diameter) no longer worked freely, and a template with 1¾ inch clearance inside, jammed about 20 feet above the bottom, showed that the bottom of the column had become distorted. The depth being too great to allow the diving apparatus to be used for investigating the nature of the accident and the ground in the bottom (a green sand with bands of clay being fairly retentive), the somewhat hazardous experiment of pumping out the water was resorted to and succeeded perfectly, the bottom being dried in two days, when it was found that the lower five rings of the tubbing were squeezed about 4 inches out of shape, the inside circle being changed to an ellipse, 16 feet 9 inches by 17 feet 4 inches, many of the segments being cracked through with the lead packing squeezed out of the joints. As it would have been dangerous to attempt to replace the defective rings the safer course was adopted of continuing the sinking with a new column of 14¾ feet inside, the thickness of the metal in the tubbing plates being increased from 2½ inches to 2¾ inches; but

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as the ground was sufficiently firm, hand work could be substituted for boring, the sinkers being protected by keeping the cylinder about 8 feet in advance of the bottom. The joint was covered by a layer of concrete, but this was made only one third of the thickness of the upper one, as the distortion of the first tubbing was attributed, not to the pressure of the ground outside but rather to the resistance offered by the thick mass of concrete above, to the free descent of the column.

The fourth or last stage of the sinking was begun in November, 1894, and on the 1st of December the carboniferous strata were reached in about 30 feet less depth than was expected, the column having been forced through the last 40 feet of the wet ground, a quicksand with marly sandstone, by a pressure of 1,500 tons acting continuously. The bearing curbs for the tubbing, which are about 15 inches broad, are fixed in a strong sandstone bed about 15 feet below the top of the coal measures, and as a further precaution a further length of five rings, about 30 feet, has been continued to the top of the walling in the shales below, and the upper end seven rings are erected within the first tubbing, the annular space between them being filled with concrete.

The sinking, including all the time lost in stoppages, was completed in three years, a result which is chiefly to be attributed to the use of the presses in forcing the tubbing down.

H. B.

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## *The Kaselowsky Pumping-Engine.*

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1896, p. 177.)

At the Schmidtmannshall Salt Mine, near Aschersleben, a water-pressure pumping-engine, on Kaselowsky's system, has been erected in the No. IV shaft. The chief difference between this and other engines of the same class is in the high-working pressure adopted, so that only a small supply of water is necessary. The pressure of 3,300 lbs. to the square inch is obtained by a steam-engine of 200 HP., working differential pumps at the surface, and is transmitted to the engine underground by a pipe of 1·18-inch bore, having a pneumatic accumulator at either end of the line. In these accumulators the power-water lifts a plunger of 6 inches diameter and 4-feet stroke, against the resistance of a piston of 15 inches diameter, moving in a closed cylinder overhead containing air, which is maintained by a compressing-pump at 600 lbs. pressure per square inch. The ratio of the two pressures, 5·5 to 1, being nearly inversely proportional to the areas of the piston, 1 to 5·6, the load on each side of the accumulator is under ordinary conditions the same.

The pumping-engine is a combination of two pairs of horizontal single-acting plunger-pumps arranged duplex fashion, one pair being in the middle while the other is at the end of the stroke, so as to ensure a continuous flow in the rising main. The plungers

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are tubes of 4 inches inside and 7·33 inches outside diameter, closed at one end, which forms the pump-piston, while the other slides through a packed joint on a central tube of 3·38 inches thick and 1·38 inch bore, through which the pressure water is admitted to the interior of the plunger during the driving-stroke, the combination being essentially an hydraulic press with fixed ram and moving cylinder. The length of stroke appears from the drawing to be about 12 inches. The plungers in each pair are coupled by side rods, so that the forcing stroke of one works the suction of the other, the pressure water being admitted and exhausted by a piston-valve worked by tappets and levers from the connecting-rods. A pressure equalizer is placed both on the admission and the discharge sides of the power water, which returns through a pipe somewhat larger than the admission (1·57 inch diameter) to the press-pumps at the surface. The water is mixed with grease in order to diminish the frictional resistance. All the joints are packed with cup leathers, which keep tight notwithstanding the extremely high working pressure.

Another example of the same engine, but of larger size, has been built for the Thies shaft of the Pluto Mine in the Gelsenkirchen district. The power is supplied by a pair of engines, 34¼-inch cylinders and 42⅓-inch stroke, with Kollmann gear, cutting off at one-fourth, which drive four 3·15-inch pressure-pumps, drawing water mixed with vaseline oil from a circulating tank in the engine-room, and forcing it into an accumulator against a resistance equal to 3,000 lbs. per square inch. The high-pressure water is carried down the shaft by a pipe of 2·6 inches bore and 0·4 inch thickness of metal, and returns by one of 3-inch bore. The engine, placed 1,647 feet underground, has two cylinders with double-acting pumps, having a patent valve gearing by Prött, of Hagen, which works without any rotatory parts, and ensures a continuous delivery from the rising main. The latter is 7·48 inches in diameter. The duty realized is 551 gallons lifted 1,647 feet per minute (nearly 275 HP.). Considerable difficulty was experienced at first from the leakage of the packed joints under the high working pressure (250 atmospheres), but these having been overcome, the engine has worked almost continuously for eleven months to the satisfaction of the owners of the mine.

H. B.

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## *Firing with Coal-Dust, and Coal-grinding Processes.*

By Messrs. Zarniko and Proppe.

(Gesundheits-Ingenieur, 1896, p. 210.)

This is an account of a discussion at the meeting of the Hildesheim Industrial Society on the use of coal-dust as fuel, which practice dates back to the experiments of Crampton in 1873. Owing to the efforts to avoid the production of smoke, attention

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has recently again been directed to this question, and experiments were conducted in February of the present year at the Moabit Infirmary, Berlin, with the various systems in which the three prominent inventors of processes for using coal-dust as fuel, namely, Messrs. Wegener, Friedeberg and Schwartzkopff, were invited to take part.

The plan advocated by Wegener has no mechanical stoking, but the fuel is fed in by a small turbine driven by the upward current in the chimney, which conveys the dust into the air-supply to the furnace; this apparatus depends rather for its action on the force of the wind and on the external temperature. Friedeberg's system requires considerable mechanical power, as the coal-dust is fed in by air-pressure under a forced draught; the action of this plant is hindered by moisture in the fuel. In the process of Schwartzkopff, a small rotary brush of steel wire, needing only $\frac{1}{10}$ HP. to drive it, supplies the powdered fuel to the combustion-chamber, and its action is quite independent of the condition of the fuel, of the weather and of the temperature.

In the case of the Moabit tests, with perfect consumption of smoke, the apparatus of Schwartzkopff gave an effective value of 80 per cent. In a sugar manufactory at Algermissen there was a saving of 22 per cent. of fuel, as compared with the ordinary combustion on fire-bars. In a cupola furnace at Vienna the saving was 45 per cent. The success of these trials had induced the Osterwald sugar factory to undertake extensive experiments, and to lay down a milling-plant by Propfe for the grinding of the coal, by the use of which dust of an extreme degree of fineness is produced.

G. R. R.

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## *On Tank-Furnaces for Glass-Making.* By E. Damour.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1896, p. 393.)

The use of open-tank furnaces working continuously, which have now almost entirely replaced pot furnaces in the manufacture of window glass, was the subject of numerous experiments, resulting in failures, in France between 1877 and 1887, until in the latter year the first successful result was obtained by Mr. Gobbe at Penchot, the experience in Belgium being somewhat similar, the Oppermann furnace of 1877 having gradually developed into that of Baudoux and Pagnoul in 1884–85, which, although its introduction was attended with rioting and the destruction of the works, has led to the abandonment of the older furnaces, there being now fifteen large and twenty tank furnaces erected, having a total heating surface of 33,600 square feet, and a productive capacity of more than 300,000,000 square feet per annum. For bottle-making the system was first introduced by Messrs. Siemens at Dresden in 1874, whence its use has spread to other countries, but the substitution is not complete as in the sheet-glass trade.

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The three principal forms of furnace in use at present are those of Siemens, Gobbe and Baudoux and Pagnoul, the two latter being generally similar in construction though varying in details. The principal element, namely, the melting basin or tank, is an oblong rectangle from 20 feet to 80 feet long and 9 feet to 20 feet broad; the depth in the Siemens furnaces varies from 24 inches to 32 inches, while in those of Gobbe it may be from 6 feet to 7 feet. The vitrifiable materials are charged at one end of the long axis, while the melted glass is drawn at the other end through working openings in a semi-circular wall, varying in number from four to twenty in the ordinary sizes up to thirty in the large double furnaces. The bottom of the tank is formed of extra aluminous fire-bricks, about 14 inches thick, carried upon brick piers and arches, or joists and iron columns, with a system of air-flues below for keeping the under side cool. The side walls are tapered in thickness, and are kept entirely free from the superstructure, provision being also made for the easy renewal of the upper layers, which are especially subject to corrosion from floating alkaline salts at the "line of salt," as the top of the bath is called.

The heating is in all cases done by gas firing, with either single or double Siemens regenerators, the former being generally adopted in the Gobbe, and the latter in the Baudoux furnace. In the illustration given of the former type, which represents one of the largest sizes in use, having a tank 75½ feet long, 11½ feet broad, and 5 feet deep, holding 400 tons of melted glass, there are nine burners on either side, extending for about 42 feet in length, which is followed by a middle settling or refinery length of 16 feet without direct heating, both portions being covered by a cylindrical arch, with 5 feet clear rise above the level of the bath, while the last length of 15 feet at the working end has a domed roof 9 feet high. Each burner has three ports superposed vertically, the gas being supplied through the middle one, and the air from those at the top and bottom. This is done to ensure regularity in the combustion, a point of extreme importance in glass-making, as the temperature in the furnace must be kept as nearly constant as possible, and the extreme variation permissible being only about 50° C. The accidental prevalence of a reducing flame, caused by too closely limiting the air-supply, damages the glass by setting up boiling, while too much air is apt to cause chilling. From the circumstance that the furnaces are constantly open, the action of the chimney-stack is confined to maintaining the circulation of the gases in the furnace, and it is practically without effect upon the producers, which must therefore be provided with their own draught, as, for instance, by the Siemens siphon or by an air-blast and closed ash-pit. The former arrangement is now generally given up, an equivalent being provided by placing the producers at a considerable depth below the furnaces; but the earlier furnaces constructed without the siphon, in imitation of those for steel-melting, before the necessity of this difference of level had been recognised, were mostly failures, as a melting heat could not be realized from the

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want of sufficient draught in the producers. For all furnaces of more than 1,600 cubic feet capacity, the double regenerator system is, in the Author's opinion, necessary; and he also considers that for moderate sizes the horse-shoe flame arrangement of the new Siemens furnace is better than the ordinary method of cross-heating, where the length of flame is limited.

The chief feature of interest, however, in these furnaces is the depth of the bath, which has been introduced by Mr. E. Gobbe upon theoretical grounds. The "metal" for window-glass when melted, being nearly colourless, is in a high degree diathermatous or permeable to luminous heat, while it is nearly opaque to that of an obscure kind, or the reverse of the conditions prevailing in steel-melting furnaces. It is therefore essential to provide larger space for the development of flame under the roof, the radiation from which, being freely transmitted downwards, is likely to attack the bottom of the tank unless a considerable thickness of absorbent material is provided above it to prevent the penetration of the heat.

This property of the glass not having been recognised at first was the cause of the failure of many of the earlier furnaces when shallow tanks were used, the bath being so completely liquefied by the free transmission of the heat that the bottom was rapidly corroded and perforated, the quality of the product being also deteriorated by alumina from the dissolved bricks. This trouble has been overcome by the bold expedient of increasing the depth of the tank to 6 feet or more. In bottle-glass making, on the other hand, where the bath is tolerably strongly coloured, a shallower tank is necessary. For instance, in the Siemens furnace, illustrated on p. 398 of the original, which has a productive capacity of 20,000 to 22,000 bottles, or about 25 tons daily, with a coal-consumption of 12 cwt. to 13 cwt. per ton, the tank is 33 inches deep, but only 25 inches of this is filled with melted glass, the bottom being protected by a depth of 8 inches of solid material, which remains unchanged throughout the whole period that the furnace is at work.

Considerable difficulty has been experienced in arranging the work about these furnaces, especially the largest ones, which should be worked continuously to ensure the fullest advantage from their use, the twelve-hour shift being too long for glass-blowers, and eight hours too short. The best period is ten hours; but this leads to irregular hours in changing shifts, which has produced great trouble; but the Author recommends its adoption, with two hours' interval at each change. At Blanzy a method has been adopted in which the furnace is worked intermittently, the charge being melted down in a first period of fourteen hours, when the work of blowing is begun with a full tank, which is completely emptied during the remaining ten hours of the day. This, though somewhat less economical than the continuous method as regards fuel, has the advantage of giving regular working hours, besides allowing the colour of the glass to be varied when necessary.

H. B.

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## *A Twyer Pyrometer for Blast-Furnaces.* By G. Brauback.

(Stahl und Eisen, 1896, p. 572.)

In this arrangement, a small cistern of about 70 gallons capacity, with a constant feed from a siphon-pipe, is placed a little above the twyer level, and two branch pipes leading out of it at the bottom maintain a continuous flow of water through two small cups in which the bulbs of two sensitive long scale thermometers are immersed. The left hand thermometer gives the temperature of the water in the cistern, while that on the right being exposed to a current passing through an 8-millimetre copper pipe placed across the goose-neck of the twyer, which forms part of the branch pipe on that side, gives a higher reading, the difference being of course proportional to the amount of water passing, and when this is constant, to the temperature of the air in the hot blast main. The instrument is adjusted by a water-pyrometer in any way that may be required, a most convenient arrangement, being such that one degree difference in the thermometers corresponds to 100 degrees in the blast. The thermometer being divided to tenths of a degree, and reading by estimation to half that quantity, the blast temperature can be obtained by inspection to within 5 degrees, which is sufficiently accurate for ordinary purposes of control. The standard should be checked by the water-pyrometer every twenty-four hours, and the apparatus must be readjusted whenever the twyer area is changed by the substitution of larger or small blast nozzles. One great advantage of this apparatus is its extreme simplicity, and the parts being readily changeable any one can make it for himself. The copper tube is scarcely affected by the hot air, and only needs to be taken out and examined at intervals of six months, which can be done in about ten minutes. This pyrometer was introduced at the Concordia Works, at Bendorf on the Rhine, in March 1895, and has been in uninterrupted use since that date.

H. B.

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## *The Niagara Calcium Carbide Plant.* By Orrin E. Dunlap.

(The Electrical Engineer, New York, vol. xxi., 1896, p. 519.)

This plant is the property of the Acetylene Light, Heat, and Power Company, of Philadelphia, and is the first plant of its kind erected in America for commercial purposes.

The start was made on April 27th. The Company claim that they can make carbide for less than £4 15*s.* per ton of 2,000 pounds, and that this figure will be improved on.

The Niagara furnaces each contain a cast-iron crucible 3 feet 6 inches long, 2 feet 8 inches deep, and 2 feet 2 inches wide. The electric furnace consists of a horizontal bed-plate, or crucible,

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connected to one pole of the generator or transformer, and of a vertical carbon pencil connected to the other pole, suspended above the centre of the bed-plate and capable of moving in a vertical direction. In starting a furnace in operation the carbon pencil is momentarily placed in contact with the bed-plate. The carbon pencil is then raised, imposing an air-gap in the circuit. Having established the arc in this manner, the material is fed in towards the crucible, covering the arc and surrounding the pencil to a depth of from 2 feet to 3 feet. The production of carbide begins immediately.

The carbide thus produced forms under the pencil and tends to close the air-gap. As the air-gap is shortened the resistance of the furnace is lowered and the load increases, which is shown by the ammeter. The attendant in charge then raises the pencil so as to lengthen the air gap, increasing the resistance and lowering the load to its normal amount. This adjustment is necessary every few minutes. After the process has been going on in this manner for from one hour to three hours, a column of carbide is formed between the bed-plate and the bottom of the carbon pencil, the arc being maintained between the top of the column of carbide and the bottom of the pencil. As the carbide formed has a comparatively high electrical resistance, and as this remains in circuit after it is formed, it is economical to stop the process, clear out the crucible and make a new start, after a column of 2 feet to 6 feet has been produced. Each of the furnaces at Niagara require some 500 HP. when at work. The carbon pencil consist of six slabs, 46 inches long, 4 inches thick, 8 inches wide at the lower end, and 6 inches wide at the upper end. They are placed side by side and clamped in a cast-iron holder connected to the dynamos. Each furnace is stated to produce about 2½ tons of carbide per day.

The article is illustrated by views of the carbide furnaces and the transformers.

R. W. W.

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## *On Diamond Carbon in Steel.* By Leon Franck.

(Stahl und Eisen, 1896, p. 584.)

The Author, after noticing the work of former investigators, especially that of Moissan, who in 1894 succeeded in crystallizing carbon in the diamond form in iron by chill casting at a very high temperature in order that the interior may solidify under the pressure of the rigid envelope, describes a series of experiments which have shown that an appreciable amount of the same substance can be found in nearly all commercial steel.

A piece of steel about 300 grams in weight is by the following treatment dissolved in nitric acid, and the residue is washed with water until all traces of iron salts are removed. This residue containing the different kinds of graphite described by Moissan, silicon

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compounds and the like, is boiled three times with fuming nitric acid, then with strong hydrofluoric acid (three times), and lastly with sulphuric acid, whereby a large part is dissolved. The sulphuric-acid solution when cooled is diluted to specific gravity 1·8, when all carbon present in the light form floats and can be poured off, while the heavy portion which is nearly free from graphite, but contains other forms of carbon, subsides. This when washed and dried is fused two or three times with potassium chlorate, then subjected to nitric, sulphuric, and hydrofluoric acid as before, the final insoluble residue being washed with bromoform. This residue, which is very minute in quantity, sinks in methyl iodide solution, showing its density to be above 3·0, and when microscopically examined is seen to consist of transparent monorefringent particles of a very high reflective power, which, when heated to redness upon a slip of platinum foil in oxygen, burn away leaving only a small amount of ash. When obtained from melted but unwrought steel these particles have the characteristic octahedral form of diamond; but when the metal has been forged or rolled the crystals are invariably broken, although in other respects the properties are the same. About fifty different kinds of steel have been experimented on, very few of which have given negative results. When the crystals are very small, *i.e.*, requiring an amplification of 2,500 to 3,000 to render them visible, there is probably a considerable loss from the strong oxidizing agent employed, so that the residue only represents a portion of the diamond carbon actually present in the metal.

The most interesting material treated by the Author has, however, been a blast-furnace bar from the hearth of Messrs. Metz & Co.'s No. III furnace at Esch in Luxemburg. This contains every possible kind of refractory compound, including iron phosphides $Fe_2P$, FeP and $Fe_3P_4$, iron arsenide, ferro silicon, maganese silicide, brilliant crystals of carbon silicide and graphite, besides titanium carbide TiC and cyano nitride $Ti_{10}C_2N_8$; the former in steel-grey, and the latter in the well-known copper-red crystals. When these are removed by boiling in a mixture of nitric and hydrofluoric acids a residue of diamonds is obtained. The largest of these, which has been named by the Author the Stone of Luxemburg, as exceeding in size any yet prepared artificially, was isolated as a completely-formed octahedron, but broke in mounting, all iron diamonds showing a great tendency to break when handled.

Two photographic illustrations, both by transmitted and reflected light, are given, but the dimensions are not stated.

The Author's investigations have been carried out in the laboratory of the University of Berne.

H. B.

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## *On the Electrolytic Desilverization of Lead.* By D. Tommasi.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 1476.)

The argentiferous lead is cast into anodes of suitable form and placed in the electrolyser invented by the Author. The bath consists of the double acetate of lead and sodium or potassium. The reduced lead is removed from the kathode by scrapers, and the silver, being insoluble in the bath, settles at the bottom of the containing vessel.

G. J. B.

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## *Hygienic Legislative Enactments against Lead-poisoning.*

By Dr. Wegener.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1896, p. 483.)

Though other poisons are known which are perhaps more terrible in their effects upon human beings, there are none more to be dreaded than lead, owing to the malignant character of its action, and the insidious methods by which it may be taken into the system. It is pointed out that it is essential that the most stringent enactments should be framed to protect the workpeople who handle lead in any form, as even the most minute doses absorbed are cumulative in their effect, and occasion ailments of widely different kinds, a list of which is given. Persons who at any time in life have suffered from lead-poisoning, although they may never again come in contact with lead, will often at a much later period succumb to symptoms which undoubtedly indicate that this poison has been stored up in the system. An account follows of the legislative measures which have already been passed to protect lead workers, and to minimize the injurious effects caused by lead in various industries. The danger of lead poisoning may arise in the following ways :—

(1) In various lead mining and smelting operations.

(2) By the manufacture of lead in different ways to form pipes, shot and printing type, and by working with leaden vessels and utensils.

(3) By the production of compounds of lead and their utilization in industries and trade-processes.

(4) By the admixture of lead with food products.

The chief methods by which lead is obtained from its ores are discussed, and it is shown that dangers to health may be caused, either by the fine metallic dust, or by the sublimed lead in the vapours evolved from the smelting operations. To obviate the mischief in the former case, efficient ventilation is of the first importance, and the evils to which the workers are exposed owing to the vapours of lead may be counteracted by condensation processes which are described. The use of respirators is compulsory in some

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cases. Analyses are given of the fumes and gases evolved in the various processes of smelting lead, and Tables of the comparative number of cases of lead-poisoning among the workers in all kinds of roasting and calcining furnaces, as also in the processes of desilverizing lead, are appended.

In the different processes of manufacturing lead, personal cleanliness is of the first importance to the workpeople, and care must be taken to prevent meals from being consumed in the workshops. The provision of spray-baths, or shower-baths on the site of the works is recommended, and in the case of certain very dangerous operations specified, milk or small beer should be supplied to the workers gratis. For the manufacture of lead paints, and of sugar of lead, very stringent regulations have been in force since April 12, 1886. The adoption of these rules has greatly reduced the cases of lead-poisoning, as is shown by statistics in tabular form. The Author considers in detail those industries in which lead is used in various ways, and indicates the precautions to be observed in each case, and the best means to combat the evils likely to arise. Statistics are given of the proportion of the workpeople attacked by lead-poisoning before and after the adoption of sundry preventive measures, and there is in conclusion a series of sixteen recommendations which cover the whole ground of these investigations.

G. R. R.

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*Researches on Tungsten.* By HENRI MOISSAN.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiii., 1896, p. 13.)

Pure tungsten may be obtained by heating in the electric furnace a mixture of 800 grams of tungstic acid and 80 grams of sugar charcoal for ten minutes with a current of 900 amperes and 50 volts. Like iron it can be welded by hammering at temperatures considerably below its melting-point. When pure it can be filed with ease, but it has the property of combining with carbon by cementation, and is then hard enough to scratch the ruby. Pure tungsten has a specific gravity of 18·7, and is not magnetic. Its melting-point is higher than that of chromium or molybdenum, but is lowered by cementation with carbon. It is not oxidized by damp air, but is slowly attacked by water containing carbonic acid.

The carbide, of which the formula is $CW_2$, is produced when the process of reduction by charcoal is carried too far. Its formation is marked by the complete fusion of the ingot. It is of an iron-grey colour and extremely hard. The specific gravity is 16·06.

G. J. B.

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## *The Preparation and Properties of Uranium.*

By HENRI MOISSAN.

(Comptes Rendus l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 1088.)

Metallic uranium may be prepared by the reduction of the chloride with sodium or potassium in a platinum crucible. It is, however, always contaminated with platinum and nitrogen, for which it has a great affinity. Owing to the strong attraction of uranium chloride for water the above process presents considerable difficulties, and better results are obtained by employing the double chloride of uranium and sodium. This double chloride may be reduced by heating with metallic sodium in the way already referred to, or it may be fused, and the uranium separated by electrolysis between carbon electrodes. It is important to surround the fused salt with an atmosphere of hydrogen to prevent access of nitrogen.

Another process used by the Author is as follows:—About 500 grams of green oxide of uranium, mixed with 40 grams of sugar charcoal, are placed in a carbon crucible and heated in the electric furnace for seven or eight minutes. If the heating has been correctly managed an ingot weighing about 350 grams is obtained.

Pure uranium is of a whiter colour than iron. It can be filed with ease and does not scratch glass. It is made yellow by the presence of nitrogen. It is not magnetic, and is much more volatile in the electric furnace than iron. In a state of powder it burns in fluorine, forming a green fluoride. It is attacked by chlorine at 180° C., by bromine at 210° C., and by iodine at 260° C. It burns in oxygen at a temperature of 170° C., and combines with sulphur vapour at about 500° C. It combines easily with nitrogen at 1,000° C., and decomposes ammonia at a red heat, and, if very finely divided, decomposes water slowly at ordinary temperatures.

G. J. B.

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## *On the Emission of New Radiations by Metallic Uranium.*

By HENRI BECQUEREL.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 1086.)

Finding that all the salts of uranium possess the property of emitting invisible rays capable of discharging electrified bodies, the Author was led to try whether the metal itself would produce the same effect. After trying the experiment successfully on the uranium powder of commerce, he obtained a disk of cast uranium from Mr. Moissan and compared its action on the electroscope of Hurmuzescu with that of a paper disk of equal size, covered with

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flat pieces of the double sulphate of uranium and potassium. The action of the metal in dissipating the charge was more rapid and more regular than that of the salt, the rate of discharge being 78·75 for the metal and 21·53 for the double sulphate, corresponding to a ratio of 3·65 to 1·00.

The Author believes this to be the first case of a metal emitting an invisible phosphorescence.

G. J. B.

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*On Vanadium: its Alloys and Applications.* By K. Hélouis.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1896, p. 904.)

In the high plateau region of the Cordillera, in the Argentine territory, at an elevation of about 14,750 feet above the sea-level, anthracite is found associated with limestone strata, dipping at a high angle, but otherwise easily workable, there being two principal seams from 6 feet to 10 feet thick extending for nearly a mile. This coal is mined in considerable quantity and burns easily, leaving when completely consumed about 2 per cent. of an amber-coloured ash containing from 14 to 25 per cent. of vanadium in the state of oxides ($V_2O_4$, $V_2O_5$, etc.), besides 16 kilos[1] of silver per ton, some zirconia, and notable traces of platinum. The Author, having devised a method for producing vanadic acid and its salts from this material, considers that it may be possible to obtain the metal from it at a comparatively moderate price for use on the large scale. Among those uses is the manufacture of aniline black, which is formed when vanadic acid $V_2O_5$, or a vanadate is heated with aniline chloride with reduction to $V_2O_4$. The latter oxide may be again made active by oxidation with potassium chlorate, so that the reaction may be often repeated without any fresh addition of vanadium. This method is useful in staining wood black, as well as for producing an indelible black writing-ink. When applied to pottery and fired at a high heat the oxides give a fine gold colour with a greenish tinge.

Of more general interest, however, are the alloys with other metals which the Author has produced in considerable variety, the point of departure being the aluminium alloy. When vanadic acid is added to aluminium, melted at a bright red heat, it dissolves, becoming progressively reduced to $V_2O_4$, $V_2O_3$, and even $V_2O_2$, but to obtain the metal a very high temperature (about 1,700° C.) is necessary. The reaction is attended with a high development of heat, the light emitted by the alloy being comparable to that of the electric arc, the proportion of vanadium in the alloys so obtained varying from 1 to 40 per cent. The 1 per cent. alloy when cast into a bar and tested had a tensile strength of 11 tons

[1] *Sic* in original; if kilograms are meant this corresponds to 522 ozs. per ton, which seems unlikely.



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with an elongation of 7 per cent. By dissolving away the aluminium the combined vanadium is isolated either in powder or in bright scales, according to the method employed.

For metallurgical purposes vanadium alloys may be produced by heating an intimate mixture of the oxides of the metals with vanadic acid and finely-divided aluminium, and in this way the Author has obtained, besides aluminium compounds, ferro aluminium-, ferro nickel- and ferro chromium-vanadium, as well as copper aluminium-vanadium alloys for experiments with bronze. In order to test the effect upon steel, a mild steel free from phosphorus, with 30 tons tenacity and 17 per cent. elongation, was melted in a black-lead crucible alone, when it became somewhat strongly carbonized, showing 61 tons tenacity and 23 per cent. elongation, which was raised by the addition of 1 per cent. of vanadium to 69 tons and 7·3 per cent., with the elastic limit of 50 tons. The same mild steel when melted in a magnesia-lined crucible to avoid absorption of carbon gave, with the following proportions of vanadium—

| —— | Tensile Strength. | Elongation. |
|---|---|---|
| | Tons. | Per Cent. |
| 0·5 per cent. (unannealed) . . . | 42·0 | 16 |
| 1·0 „ „ . . . | 61·5 | 14 |
| 1·0 „ (annealed) . . . . | 45·0 | 20 |

The latter metal although very soft when annealed becomes extraordinarily hard by tempering.

Ordinary malleable iron of about 24·5 tons tenacity and 19 per cent. elongation was changed by the addition of 0·5 per cent. of vanadium to 39 tons, and 12 per cent. in the forged bar, and 33·7 tons and 32 per cent. elongation when annealed. The latter result has attracted considerable attention for the remarkable malleability and ductility indicated.

Aluminium bronze with 8 per cent. of aluminium and 1 per cent. of vanadium has a tensile strength of 45 tons with 12½ per cent. elongation. The Author has applied the same method of reduction with powdered aluminium to other oxides, including those of nickel, chromium, manganese, and tungsten, the reaction being in all cases very energetic and often almost explosive. The most violent action takes place with molybdenum, 500 grams of molybdic acid when raised to a bright red heat, in contact with aluminium, giving a louder report than that of a gun, with projection of the melted metal from the crucible. With care, however, the reaction may be subdued to a prolonged deflagration, and ferro molybdenum obtained with as much as 77 per cent. of molybdenum. Steel containing 0·5 per cent. of the latter element is extraordinarily hard.

H. B.

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## *A Method of Restoring the Surfaces of Oxidized Copper Objects.*

By F. RATHGEN.

(Dingler's Polytechnische Journal, vol. cccl., 1896, p. 45.)

In carrying out some earthworks near the Church of St. Maria in Capitolia at Cologne a quantity of Roman copper coins, amounting to between 40,000 and 50,000, was found, but most of them were so much corroded and encrusted with blue and green carbonates that the effigies and inscriptions could not be determined. These having been sent to the Author for cleaning, he, after trying a great number of methods, decided upon one based upon that used by Axel Krafting for the removal of rust on iron antiquities in Sweden, namely, reduction by the joint action of zinc and caustic soda, which was carried out as follows:—

A piece of thin sheet zinc with a bright metallic surface, perforated by a needle with from fifty holes to sixty holes to the square decimetre, is placed upon a glass trough with the burrs uppermost, and upon it are laid the coins, about seven or eight to the square decimetre, with a similar plate covering them, and so on up to the height of six or eight double layers, the top zinc being placed with the sharp edges of the holes downwards. The pile is then covered with a 4 per cent. caustic soda solution, which causes a vigorous evolution of hydrogen, which in from fifteen hours to eighteen hours completely reduces the oxidized crust, the zinc oxide produced at the opposite electrode passing, wholly or in part, into solution in the alkaline liquor. After careful washing in cold and hot water, continued for four days, the coins are dried at 100° in a hot closet and finally brushed to remove the dusty metallic deposit, when they appear with a brown surface generally like that of copper coins in ordinary use. Another method of reducing the copper oxide, communicated to the Author by Dr. Kisa of Cologne, consists in plunging the coin, held in a forcep, into melted lead until the crackling noise, usually lasting from three seconds to ten seconds, ceases, when it is thrown into cold water, cleaned, and left overnight in hot milk. This gives an olive-green tint to the surface, which is by most collectors preferred to the dark brown of the other process, which should, however, be used when it is desired to recover inscriptions, as in all but a very small percentage of the coins treated by the Author the devices and inscriptions were perfectly recovered when the electro lytic method was adopted.

H. B.

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## *Storage Battery Manipulation on Variable Loads.*

By J. E. WOODBRIDGE.

(The Electrical World, New York, vol. xxvii., 1896, p. 673.)

The use of accumulators for regulating and storing purposes in connection with central station supply has become admittedly of great importance, notably so in cases where the supply is intended for electric traction, owing to the heavy fluctuations in the load. There are however some considerable difficulties inherent to their employment, principally because the dynamo generators in an electric tramway power-house are as a rule over-compounded to secure an approximately even pressure at full load. The Author examines the various methods that have been devised to ensure satisfactory working when the batteries are in parallel with the generators, being charged at times of light load, and giving current when the system is overloaded.

In electric-lighting stations, regulation of the batteries is maintained by cutting in or out some of the cells either automatically or by hand. This is not satisfactory, however, for many and obvious reasons, and a better plan is to put in a special low voltage dynamo (called a "booster") in series with the battery across the mains, its field carrying the entire external current. As the load on the mains increases, the booster automatically raises the battery voltage and causes discharge on heavy loads. Another arrangement is to connect the booster as before, but arrange its field in parallel with the main generator series field-coils between the positive omnibus-bar and the equalizer.

The best method, in the Author's opinion, is to arrange the booster as last mentioned, with the addition of a shunt-winding on its field-coils. It then works both ways—when the load is light the shunt-field predominates, and the booster helps the main dynamos to charge the battery; with a moderate load the booster becomes idle, but with a heavy load its polarity is reversed, and it helps the battery to discharge and relieve the dynamos. By regulating the booster field the regulation of battery action is easily and properly carried out. The booster should be coupled direct to a shunt-motor, not worked from a steam-engine.

F. B. L.

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## *Peschel's Electric Wiring System.* By F. UPPENBORN.

(Elektrotechnische Zeitschrift, 1896, p. 364. 21 Figs.)

This system, worked by Messrs. Hartmann and Braun, consists of the employment of double flexible wire, supported by porcelain insulators, carried upon metal hooks of special form. The earliest form of hooks was found to be too weak; and the improved form

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consists of a hard steel tapered nail of square section screwed where it projects from the wall. It is driven in by means of a tubular punch, thus protecting the thread. A rosette provided with a stout hook screws on to the thread. It is stated that the nails are put in before the decorations of the building are finished and the wires fixed up afterwards. In the case of ceilings, long slender hooks with screwed ends are used to go into the joists.

Several methods of carrying the wires are adopted. One method consists in using a split insulating ring, grooved outside, and of such a size as to fit tightly in the spring hook of the carrier. A flat I-shaped piece of hard rubber is pushed between the two twisted wires, the two halves of the ring are then put over it, and the ring pressed into the hook. It will be seen that in this way all sag can be taken out of the line of wire. If the twist of the wires is very quick, or if a single wire is dealt with, nicks are cut in the hard rubber. Three or four wires can be carried together by using two I pieces notched longitudinally. Solid rings can be used if the hard rubber be made T-shaped and provided with a split pin.

Another form consists of split rings with two separate tapped holes which grip the insulated wire. A special tool is provided for forcing the rings into and out of the strong spring hooks. Special wall drills of star-shaped steel are made, and tapered wood plugs, both of round and square section, are provided.

E. R. D.

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*A New Form of Electro-dynamometer.* By R. JACQUEMIER.

(L'Industrie Électrique, 1896, p. 224.)

The instrument described by the Author, or rather the principle upon which it is based, involves the application of a pivoted movable coil lying between two fixed coils, being itself counterbalanced and also attached to a counterbalanced parallel motion; the latter multiplies the movement of the coil, and, by means of a toothed sector or quadrant, actuates a gear-wheel, upon the axle of which is carried the index figure.

The scale is almost evenly divided throughout its entire range, the force acting through the coil being very nearly proportional directly to the index movement round the scale, owing to the particular arrangement and proportions of the various lever arms operating the mechanism.

The Author enters into an elaborate mathematical examination or proof of the method underlying the action of this instrument, and shows how to avoid the errors that would otherwise ensue. He considers that it can be used in one or other of the forms he illustrates and describes both as a laboratory appliance and engine-room meter, reading either in watts, volts or amperes,

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automatically and proportionally; and even as an erg-meter, or energy-counter. Its great advantage seems to lie in the absence of springs and permanent magnets; by experiment the greatest error in reading has been found not to exceed 0·9 per cent.

F. B. L.

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*An Electroscope with Three Gold Leaves.* By L. Benoist.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiii., 1896, p 171.)

The Author's modification of the gold-leaf electroscope differs from the ordinary form in being furnished with three strips of gold leaf instead of two. This arrangement makes it easier to read the angle of divergence against a divided circle, as the central leaf, which remains vertical, serves as a reference line and facilitates the centering of the scale. The sensitiveness of the instrument is increased in the proportion of 1 : 1·49 for small angles. When fully charged, the two outer leaves make an angle of 120 with the vertical.

G. J. B.

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*Measuring Power in Three-phase Circuits.*

By Dr. Behn Eschenburg.

(Elektrotechnische Zeitschrift, 1896, p. 182.)

This note describes a method of measuring the watts in a three-phase circuit (even when unequally loaded). An ordinary Siemens or Ganz watt-meter is employed, or a Siemens electro-dynamometer. The current in one leg of the three-phase system passes through the fixed coil of the instrument. Branches from the other legs each contain a subsidiary resistance, and meet at the terminal of the moving coil shunted from the first leg. It is stated that the watt-meter readings give a direct measure of the total power in the three-phase system although the legs may be unequally loaded.

F. B. L.

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*On the Disturbances caused in Telephone Circuits by Powerful Currents.* By Dr. v. Wietlisbach.

(Elektrotechnische Zeitschrift, 1896, p. 252.)

The Author refers particularly to disturbance caused in telephone wires by fluctuations of current on street-railway circuits. As the telephone lines have been in use now about fifteen years little had been done in street-railway work when they were first installed.

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At first the telephone industry strove to prevent the railway companies from working; but it was obvious that the former industry had no exclusive right to use aerial lines. The telephone companies cannot be expected to so design their plant as to avoid all the troublesome effects caused by powerful currents. A telephone wire may come in contact with a wire carrying a heavy current, and the former wire may be melted and cause great damage. Part of the heavy current may go by earth to the telephone wires. If the current be constant, as from a battery, it causes little disturbance although it decreases the sensitiveness of the telephone; but if the current be undulating, as when used for motors; or alternating, then there is more or less humming produced.

The Author describes the effects of induction on neighbouring wires, and afterwards proceeds to deal with the means for diminishing or guarding against the effects. There are the cut-outs, where the wires enter the telephone station, and these melt if the current exceeds 1 ampere. There is little difficulty in making them more sensitive, but probably they would then melt in case of storms.

If the pressure in the high potential wires be over 500 volts an arc is formed after the melting of the fuse, and this may be more dangerous than the current itself, but it is counteracted by means described by the Author.

Humming in the telephone wires is to be avoided by well insulating these wires, and also the high tension mains, from earth and from each other.

Induction gives the greatest trouble. The Author advises metallic returns for the telephone; but if the induction is very great the high potential leads should be doubled also. He then considers the case of four wires carried on the same poles, figured respectively 1, 2, 3 and 4, the first two being high potential wires and the latter two telephone wires; then, if the distances apart be $r_{13}$, $r_{23}$, $r_{14}$, $r_{24}$, the relation $r_{13} \times r_{24} = r_{23} \times r_{14}$ must hold good to avoid induction. He then brings out clearly the necessity for perfect insulation, and instances the case of the Zurich street-railways, which cause induction effects which may be felt all over West Switzerland. As the Swiss telephone network is about 37,200 miles in extent it is no small work to keep the whole in perfect insulation. Often the only feasible method is to put the wires underground. Another method is to separate the telephone wires into sections and work along these sections by induction through "translators," just as transformers are used with heavy currents. One portion is then not affected by the faulty insulation of another; but the working capabilities of the line are diminished, as the efficiency of "translators" does not exceed 90 per cent.

The Author then considers the question of the effects produced by the relative positions of the heavy-current wire and the telephone wire, and points out that it is sufficient for one of the former wires, if connected to earth, or having bad insulation and

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carrying an alternating current, to cross one of the latter at right angles to cause humming to be heard. In Switzerland there is one street-car line, the Vevey-Montreux-Chillon, which uses an overhead return wire. All other lines use the rails as the return, and the insulation resistance of the rails is often only about 24 to 32 ohms per mile; but this could be improved if they were bedded in cement or asphalt. Experience seems to show that the rails are at present better insulated in wood-paved streets than elsewhere. The Author suggests insulated cable returns connected to the rails and copper bonding, while in the worst cases the telephones should have metallic returns.

Induction effects are difficult to deal with, for if the commutator segments of the motors are increased the humming on the telephone wires is merely raised in pitch. Another cause is the varying contact of the trolley and the wire.

Although street-railways may be constructed on the same plan each produces its own particular effect on the telephone wires, small at first but gradually increasing. Trolleys produce much worse results than the sliding bow contacts, tight wires than loose wires. The Author points out that some street-railways produce very little effect on the telephones, while others are very bad; the causes of the variation should be looked into.

In the case of a street line using polyphase current, and having two overhead wires, and the rails as the third wire, it has been found necessary to put the telephone wires underground.

E. R. D.

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*The Central Station of the United Electric Light and Power Company.* By H. W. York, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, July, 1896, p. 429.)

The United Electric Light and Power Company supply electricity for all purposes in the city of New York. The stations which the new company acquired and attempted to operate had all been doing service for several years, and the apparatus was naturally somewhat antiquated. After making numerous changes and improvements in the methods of generation and distribution of current it at last became necessary to erect a new station to take the place of the old ones, and to embody as far as possible the best modern practice for the economic generation and distribution of current.

The first half of the station has been erected under the superintendence of the Author, and the apparatus installed has been in operation since September, 1895. Economy of space, where land is so expensive as in New York, being one of the first matters to consider, it was arranged that the station, to contain 20,000 HP. of engines, together with boilers, pumps, condensing apparatus, dynamos, switchboard and storage for 6,000 tons of coal, should be

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erected on a plot of ground 170 feet by 197 feet 6 inches. All the machinery, including the boilers, is on the ground-floor, and yet there is plenty of light and ample space for making repairs to the apparatus. The building already erected has a frontage of 170 feet; it is a steel-framed structure with brick filling in the walls except at the north end, which is temporarily covered with a corrugated iron screen to allow for the extension. The front wall is hollow, being composed of two walls: one, on the outside, 12 inches thick, and the inside one 8 inches thick, separated by a 2-inch air-space and connected together by binders. It is carried up above the roof to prevent the noise annoying the patients in the Bellevue Hospital, which is opposite. Double windows are also used on this side of the building. This arrangement has been entirely successful in cutting off the noise. The foundations of the building and of the machinery rest on the solid rock. The foundations of the walls are kept 1 inch away from those of the adjoining buildings in order to avoid vibration and the space filled with sand up to ground-level, above which the adjoining walls were covered with tarred paper, and the brickwork built against this to prevent the possibility of any bond. The foundations of the eight main engines and dynamos were built for four together on each side, of hard brick in cement mortar. The engine and dynamo room is spanned by an electric crane of 25 tons capacity, which has a span of 72 feet 4 inches.

The boilers are of the upright water-tube type, arranged in batteries of 600 HP. This kind was chosen both on account of its efficiency and the small space it occupies. Three feed-pumps are provided, any two of which can supply all the boilers.

The coal is filled into buckets, on an endless chain at the street-level, and carried up into the ventilating-chamber over the coal-bunker, which is situated over the boiler-room, and dumped into any desired position. From hoppers in the bottom of the bunker the coal runs down spouts to the boilers without assistance. The ashes are likewise collected under each boiler into a hopper, whence the conveyer carries them to the street-level.

The type of engine adopted is the Westinghouse double-acting. The low-pressure cylinder is placed over the high-pressure cylinder, and both pistons are connected to the same rod. The low-pressure valve is a slide-valve operated by an eccentric, while the high-pressure valve is of the hollow piston type, so as to allow the exhaust from the lower end of the cylinder to pass through it; it receives its motion from a shifting eccentric operated automatically by a governor. The valve is cushioned by a plunger actuated in the same manner. The diameter of the high-pressure cylinder is 21½ inches, and that of the low-pressure cylinder 37 inches, with a common stroke of 22 inches. The initial steam-pressure is 150 lbs. on the square inch, the revolutions 200 per minute, and the HP. when condensing 1,200.

The steam-pipes are arranged so that the sizes required are the minimum, and so that, without going to the expense of duplicating

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them, the connection between the pipe and any boiler or engine can be shut off without affecting any of the others. A 16-inch diameter pipe of steel boiler-plate runs the whole length of the boiler-room, and a similar one, parallel to the former, the length of the engine-room between the two rows of foundations. These are divided into five sections by means of four steam-valves, and each section of the boiler-room main is connected to the corresponding section of the engine-room main by a 14-inch wrought-iron branch-pipe fitted with a valve. Each boiler has an independent connection to the boiler-room main by means of a similar pipe provided with two valves—one just beyond the safety-valve, and the other at the point where the pipe enters the main. Each engine is supplied by a 14-inch branch of the engine-room main. A combined steam separator and receiver is fixed as close to each engine as possible. It contains six times the volume of the high-pressure cylinder, *i.e.* eighteen times the volume of steam required with the latest possible cut-off. This maintains a practically uniform flow of steam in the pipe in one direction only, permitting the use of smaller pipes than would otherwise be required. Low points are arranged on the steam-pipes, to which the condensed water gravitates, and it is returned to the boiler. Expansion in the steam-pipes is provided for by long bends and swinging elbows, no expansion-joint being used. The steam-pipes were tested to 300 lbs. on the square inch with cold water.

Each main engine is directly connected by a rigid coupling to a 600 kilowatt Westinghouse alternator; both engine and generator being set on a firm cast-iron bed-plate. The generator has only one bearing, the armature being swung between the engine and this support. The armature is slotted instead of toothed, and there is an almost entire absence of noise. The alternators are arranged to give either a single or two-phase current. This is accomplished in two of the machines already in place by two separate armatures in the same shaft, set at the proper angle in relation to each other to give the form of current required. In other two of the alternators already fixed the same result is accomplished with a single armature. For exciting the fields of the alternators 75 kilowatt direct-current Westinghouse dynamos of the railway generator type are used, worked by a separate engine. The lead wires from the machines consist of lead-armoured cables run in iron ducts directly from each dynamo to its panel of the dynamo-board, where each alternator and exciter has its own panel, equipped with the customary appliances, including volt-meter, am-meter, rheostat, fuse-blocks, switches, etc. The entire distribution system is underground, and includes about 150 miles of ducts. The voltage is reduced to any desired pressure by means of converters. Continuous registering meters of the Shallenberger type are used to determine the amount of current consumed.

A. W. B.

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## *The Düsseldorf Electricity Works.*

(Elektrotechnische Zeitschrift, 1896, p. 214.)

The following particulars are given in the report on the municipal electricity works at Düsseldorf for the year 1st April, 1894, to 31st March, 1895:—In the year the number of lamps connected rose 13 per cent., from 17,967 to 20,369, each of 53·5 watts. The output rose 11 per cent., from 351,708·7 to 390,628·1 kilowatt-hours. A still larger increase took place in the supply of current for power purposes; while in 1893–94 only 6 HP., with 1,635 kilowatt-hours, were supplied, at the end of 1894–95, 27 HP. were supplied, with a consumption of 5,565 kilowatt-hours; 40 HP. more is demanded, and other orders are expected. The price of current was reduced on the 1st of January, 1895, from 10·8*d.* to 9·6*d.* per kilowatt-hour. Details are then given of the revenue of the station, which reached the total of £12,506 in the year 1894–95. The price received was 5·3*d.* per kilowatt-hour produced and 7·68*d.* per kilowatt-hour sold, allowing for discounts.

The four boilers worked altogether 6,741 hours in the twelve months. The total weight of coal used was 1,247·2 tons; and 1 HP., or 660 watt-hours, were produced for the following weights of coal:—Current production, 3·26 lbs.; current delivered, 4·7 lbs., or 1 lb. of coal generated 203 watt-hours, of which 140 watt-hours were actually used. The coal cost 8*s.* 8*d.* per ton. A great number of details are given in the form of a Table, from which the following have been abstracted. The largest output was 3,595·7 kilowatt-hours, on the 22nd of December, 1894, and the smallest 416·2 kilowatt-hours, on the 15th of July, 1894. Taking the year as a whole, 43·5 per cent. of the output was produced by the machines direct, and 56·5 per cent. by the accumulators. The commercial efficiency of the accumulators is given as 77·31 per cent. The connections on the 31st of March, 1895, were 14,993 glow-lamps of 53·5 watts, 795 arc-lamps, 14 electric apparatus and 14 motors, making an equivalent total of 20,369 glow-lamps of 53·5 watts.

The costs of production were as follows per kilowatt-hour:—

| | Produced. | Delivered. |
|---|---|---|
| | *d.* | *d.* |
| Wages | 0·37 | 0·535 |
| Coal | 0·29 | 0·42 |
| Oil waste, etc. | 0·04 | 0·052 |
| Tools, etc. | 0·08 | 0·115 |
| Salaries | 0·32 | 0·485 |
| General expenses | 0·065 | 0·09 |
| Repairs | 0·015 | 0·015 |
| Accumulator maintenance | 0·24 | 0·35 |
| | 1·420 | 2·062 |

The remainder of the Paper deals with the original cost of the plant and financial details. E. R. D.

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*The Rheinfelden Power Transmission Plant.* By E. RATHENAU.

(Elektrotechnische Zeitschrift, 1896, pp. 402–409. 7 Figs.)

The Author is the managing director of the power company of Rheinfelden, and the Paper was read at the fourth annual meeting of the Verband Deutscher Elektrotechniker at Berlin. He refers to the success of the Lauffen Frankfort transmission plant, and states that in July, 1889, a preliminary company was formed in connection with the Allgemeine Elektricitäts Gesellschaft. This company had some difficulties, as the Rhine here divides Baden from Switzerland, and each of the two states desired the offices of the company to be within its own boundary. It was agreed that a flow of 1,760 cubic feet of water per second should be left in the Rhine bed. With respect to taxation the Canton Aargau will receive a fixed annual sum, while Baden will draw the trade and income taxes. It was found difficult to collect the full capital, so a part only of the work was taken in hand, as the concession would expire at the end of 1893.

The report of Prof. Intze of Aachen confirmed the opinions of the founders, as he stated that the installation cost would not exceed £15 per brake-HP. on the turbine shaft. The Rheinfelden Power Transmission Works Company, Limited, was therefore formed with a capital of £200,000. The contract for buildings and turbines was let to the company, formerly Escher, Wyss & Co., of Zurich, jointly with the firm of Zschokke & Co., of Aarau, Prof. Conradin Zschokke being the building director, and Prof. Intze the Consulting Engineer.

Dealing with the water-power, the Author states that at the junction of the Aar there is a fairly constant volume of 12,400 cubic feet per second, and between Beugger-See and Rheinbrücke there is a stretch of 2,610 yards, with three rapids, having a total fall of 21·5 feet to 24·5 feet. In the first scheme it was proposed to use the whole fall, but it was found that it would be necessary to expend £500,000, obtaining 11,000 HP. The portion, therefore, between Beugger-See and Theodorhof only is being used.

The first scheme entailed the use of fifty turbines placed in a row near the Baden bank of the river. These were to be arranged on a floor carried by vaulting over the tail-race, and two turbines were to drive each dynamo by gearing. The final scheme differed in having a wider canal, the vaulted tail-race chamber was done away with; only twenty turbines were to be used, one turbine to drive each dynamo, and each turbine chamber was to be entirely separate from its neighbours.

The scheme was accepted in April, 1895, by the Baden and Swiss Governments, and work was begun. Observations of the Rhine during eleven years showed that the smallest average water-power was 13,800 HP., and each of the twenty turbines will give 840 B.HP., so that a reserve is obtained over the maximum water-power

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taken at 18,000 HP. A concession also gives the right to use 7,000 HP. more by the water-power to Rheinbrücke.

The dam is placed square across the stream and founded on the solid rock; its upper surface is 294 yards long, and it has a by-pass 21·8 yards wide, the bottom of which is 4·4 feet below the top of the dam. This must always be left open to allow of the passage of rafts and to ensure the flow of 1,760 cubic feet of water per second. The dam will have a top breadth of 6·56 feet; it will have a long slope on the up side and a more rapid fall on the down-stream side. The dam is tied into the bank on the Swiss side where the bottom is not very good. A fish ladder 9·8 feet wide is arranged near the by-pass.

The power canal has a width of 164 feet at the bottom, and in the middle there is a gutter for collecting the silt, while at the upper end there is a pebble and stone catcher.

To prevent the accumulation of ice near the turbine chambers, and to allow for clearing out the silt at the bottom of the canal, a special sluice, 9·85 feet wide and 51·5 feet long, is made, provided with a pivoted door. The tail-race is cut out of the solid rock, and the Swiss bank of the river is protected against the wash of the tail water. The building work was only carried out with difficulty. Each turbine has its special chamber, 18 feet wide, 32·8 feet long, and the division walls are each 4·1 feet thick. Each chamber is provided with a pair of iron-plate flood gates, 9 feet wide by 16·40 feet high, turning on a central pin. The pins are designed for a water-pressure of 154,000 lbs., and are closed from above by wheels. In case of repairs they do not close tightly enough to exclude all the water, and this is dealt with by centrifugal pumps worked by electric motors.

The dynamo chamber is 490 feet long by 32·8 feet wide, with workshops at each end. The total height of the building is 78·5 feet. The machine room is 26·2 feet in the clear, and it is served by a 40-ton electric crane.

In the first scheme it was proposed to use Jonval turbines running at forty-four revolutions per minute and each developing 330 HP.; but as the fall at flood is only from 8·2 feet to 9·8 feet, and at low water 16·4 feet, and the water passing varied from 600 cubic feet to 800 cubic feet per second, it was necessary to choose turbines of large diameter and low speed, and finally the Francis reaction-turbine was selected as least costly. Each turbine consists of two separate wheels, so that there are four discharges. The maximum efficiency is obtained with the highest fall, but in flood the use of more water is no disadvantage.

The Author gives details of the construction of the turbines. The dynamos are driven direct off the vertical turbine shafts, and the bearings are of guaiacum wood. The efficiency of the turbines at normal load is 75 per cent. The electrical part of the plant was most carefully studied, and the Author goes at some length into the question of choice of system. Finally three-phase current, with a frequency of fifty periods per second, was chosen. As the area

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of supply had a radius of 12·4 miles, a potential difference of 16,500 volts was considered advisable; but as only a light load could be expected at first a pressure of 6,800 volts was decided upon.

The type of machine chosen has a fixed armature and a rotating wheel carrying the pole pieces; the vertical shaft is carried in bearings above and below the rotating part, the lower bearing carrying the whole weight of the turbine and dynamo. The ring-shaped frame is 23 feet in diameter, and consists of four parts to facilitate transport.

The normal output of each machine is 63 amperes at 3,800 volts per phase and 720 kilowatts. With a phase lag, $\cos \phi = 0 \cdot 8$, about 580 useful kilowatts would be produced, needing 840 HP. at the shaft. The efficiency of the combined plant, inclusive of energy used in exciting, is 92 per cent. in spite of the low speed.

The supply of current for light and that for power will be kept quite separate, and it is expected that four sets will be used for lighting and fourteen for the supply of power, about half the latter being for chemical works.

It is proposed to raise the pressure to 16,500 volts by means of primary transformers when the demand for current is sufficiently great. Three rotary transformers, each of 150 HP., are used to convert the three-phase current into direct current for exciting the machines and for charging a small set of accumulators. A map of the district supplied is given in the original, the mains extending beyond Basel on the Swiss side and beyond Zell on the German side.

The secondary network in each case will have a potential of 2,000 volts, and this will be again reduced to 120 volts for lighting and 500 volts for power.

The primary main of bare copper will be carried on poles, and a detailed description follows of the methods used.

The scale of charges for lighting current begins at 4·8*d.* per kilowatt-hour, but there are discounts up to 80 per cent.; for power the charge is 1·92*d.* per kilowatt-hour, but besides this a ground rent is charged varying from £2 12*s.* to £8.

The Author proceeds to compare the relative losses in electric-motor driving and steam plant, and gives the former 50 per cent. advantage. He feels assured that the district will become the seat for many manufactures, and cites the case of two large establishments, branches of the Neuhausen Aluminium Works in Bitterfeld, which have just been started.

E. R. D.

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## *Electric Lighting and Power-Transmission in Messrs. Oldenbourg's Printing Works, Munich.*

(Elektrotechnische Zeitschrift, 1896, p. 331. 5 Figs.)

Various illustrations in the original text show the arrangement of these works. In the boiler-house there are two water-tube boilers, each having 897·5 square feet of water-covered heating surface, and built for a pressure of 140 lbs. per square inch; these supply steam both for the engines and for heating purposes. The feed-water is passed through a purifier, and the condensed water is raised to the level of the sewers, after having passed through an oil separator. The engine-room is built to accommodate two engines, of which only one is yet installed, of the single cylinder type with Proell gear, giving 55 HP. normally and a maximum of 70 HP. at a speed of 85 revolutions per minute. The engine has a double fly-wheel, and drives direct, by two belts, a pair of direct-current shunt-wound dynamos, each giving 24 kilowatts and 120 volts at 350 revolutions, and 150 volts at a higher speed for cell charging. Two dynamos rather than one were chosen in order to separate the light- and power-work, and permit of charging a Hagen battery of sixty cells with a capacity of 926 ampere-hours for a ten-hours' discharge. Distribution boards carry all fuses, switches, etc. The lighting of the works and several private houses requires 500 16-candle-power lamps and thirty 8-ampere arc-lamps. Composing and colour-printing require first-rate illumination, and arc-lamps, with inverted hemispheres of opal glass, are used, so that the bulk of the rays are directed upwards and reflected downwards from the white painted ceiling.

The motor question was very important, and careful tests and calculations were made to see whether a centralized plant or separate motors would be best. The latter method was preferred. A fourteen-days' test of thirteen rapid presses and two calenders, which should require 12 HP. if all were used together, showed that in one day, during ninety-eight observations extending over 12·5 minutes, there were 7·6 machines in use consuming 5·84 HP., while 6·4, taking 4·2 HP., were idle. In spite of this the whole shafting, taking 3 HP., had of course to run. The same was found to be the case in the stereotype and plating departments, so that separate motors were decided on, except for the bookbinding department, where twenty-four machines require only 5 HP. All the motors are of the low-speed shunt type, by Siemens and Halske, and give a total output of 41·3 HP.; they drive fifty-four machines, and vary in size from ½ HP. to 5 HP. The motors are not rigidly fixed on the base; but each is carried on a hinge at one side and rests on a spring at the other, thus keeping the belt tight.

The advantages of the system are proved as follows:—Formerly



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there were twenty-six machines taking 16·5 HP., and the gas-engine had to develop 18 HP.; now the steam-engine develops 17 HP. and drives thirty-two machines taking 25 HP. Other details follow, and the Author particularly draws attention to the fact that the workmen soon got used to the new arrangement, which has been a great success.

E. R. D.

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## *On Viscous Dielectric Hysteresis.* By Riccardo Arno.

(L'Éclairage Électrique, vol. vii., 1896, p. 407.)

Previous experiments of the Author on the rotation in a revolving electrical field of a cylinder formed of a dielectric, and on the dissipation of energy in a dielectric under such conditions, show a lag between the rotation of the polarization of the dielectric and that of the revolving field. This may be due either to the dielectric constant having smaller values for an increasing electrical field than it has for one diminishing, or to a time interval between the attainment by the dielectric of the value of the polarization corresponding to the field and the instant of its appearance. The Author is of opinion that the latter is the cause, at least in part, and he calls the phenomenon "viscous dielectric hysteresis."

The experiments of various investigators are adduced in support of this view. Those described by the Author in this Paper were undertaken with a view to determining whether the observed phenomenon could be wholly accounted for in this manner or not.

| Strength of Field. | Frequency. | Deflection. |
|---|---|---|
| | | Millimetres. |
| 0·083 | 44 | 5·5 |
| | 22 | 9·5 |
| | 11 | 13·5 |
| 1 818 | 44 | 59·0 |
| | 22 | 87·0 |
| | 11 | 129·0 |

For a revolving electrical field the viscous hysteresis is a function of the speed of rotation of the field, and, therefore, the existence of such a phenomenon will be established if the intensity of the field be kept constant while the speed of rotation is varied. The revolving field was obtained by means of two alternating fields of equal intensity at right-angles to one another and differing in phase by 90°. Since the period of rotation of the resultant field was equal to that of the alternating current it was only necessary to vary the frequency of the latter in order to alter the speed of

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rotation, the two fields being constant and equal. Two strengths of field were employed, viz., 0·083 and 1·818 C.G.S. electrostatic units. The dielectric was paraffin in the form of a hollow cylinder 1·18 inch external diameter, 0·039 inch thick, and 1·02 inch high, having a mass of 31·03 grains. The deflection was read by means of a telescope. The results are given in the Table on the preceding page.

The Author concludes that the energy dissipated each cycle in the cylinder varies with the speed of rotation of the field, and therefore this dissipation is due, at least in part, to the effect of viscous dielectric hysteresis in the material experimented upon.

C. H. W.

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*The Physiological Action of High-frequency Currents, and the Means of Producing them Continuously.* By A. D'Arsonval.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiii., 1896, p. 18.)

This Paper contains a description of the Author's apparatus for generating high-frequency currents, which is capable of working for several days without attention. In the arrangement used by Hertz and perfected by Tesla, Elihu Thomson, and the Author, a condenser is charged periodically by the high-tension alternating current from a transformer. This condenser discharges itself through a circuit of suitable resistance and self-induction, and generates in so doing a series of electrical oscillations. If a fairly strong current is used in the transformer, great inconvenience arises from the fact that the knobs of the discharger are also in connection with the transformer circuit, so that every spark which passes forms an arc, wasting the current and deteriorating the apparatus.

The Author avoids this difficulty by placing in the high-tension circuit of the transformer a condenser of variable capacity, which he calls the guard-condenser, in series with the condenser to which the discharger is attached. Thus the secondary circuit of the transformer is always open, and by suitably regulating the capacities of these condensers the sparking is brought under control. A still further improvement is effected by interposing in the primary circuit of the transformer a coil with adjustable self-induction. With this arrangement the Author was able to produce with a current of 3 amperes the same results for which hitherto a current of 30 amperes had been required.

Some trouble was experienced with the Leyden jars used as condensers, owing to the heating and consequent rupture of the glass, until the plan was adopted of filling them with water covered with a layer of vaseline oil.

In the observations upon animals, of which the interest is mainly physiological, it was necessary to have some measure of the oscillatory currents actually generated during each experi-



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ment. This was effected in the following manner:—The conductor conveying the electrical oscillations made fifteen or twenty turns round the horizontal, cylindrical, non-conducting cage in which the animal was confined, thus constituting the primary of an inductorium of which the secondary consisted of the body of the creature, which would thus be traversed by induced currents of high frequency. The conductor itself was composed of a tube filled with air, the expansion of which, indicated by a manometer, afforded a measure of the heat generated, and consequently of the amount of current.

The Author finds that, although these oscillatory currents produce no effect whatever upon the sensations, they have a marked influence upon the secretions and excretions.

G. J. B.

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## *On a New Electrolyser.* By D. Tommasi.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 1122.)

This electrolyser consists of a rectangular vessel containing a pair of anodes, between which a metallic disk, half immersed in the liquid, revolves slowly. The spongy metal deposited upon this disk by the action of the current is rubbed off by a pair of scrapers, and collected in receptacles provided for the purpose. The anodes may be either in the form of plates or of a coarsely-granulated powder contained in perforated cages, with a sheet of metal serving as a conductor. The Author claims that with this method polarization is entirely suppressed by the rotation of the disk and by the action of the scrapers, and that by the removal of the metal as fast as it is deposited the oxidizing action of the bath is minimized and the possibility of short circuiting prevented, so that the plates can be brought much closer and the resistance of the cell reduced. A further advantage is that, in consequence of the continual motion, the liquid remains of the same density throughout.

G. J. B.

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## *Recent Developments in Vacuum-Tube Lighting.*

By D. McFarlan Moore.

(Transactions of the American Institute of Electrical Engineers, 1896, p. 430.)

This Paper was read in a room lighted by vacuum tubes. The room held some 150 people, and printed matter could be read in any part of it. The Author commences by reviewing the past history of attempts to obtain light from vacuum tubes, and states that, although vacuum tubes are a most efficient means

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of lighting, the intensity of the light has previously been too feeble to be useful. The apparatus mostly used for the above purpose has been the induction coil, and a current of low potential has been supplied to the primary, because a current of high voltage could not be properly disrupted. The formation of an arc in such cases prevents a sudden break of the current. The Author considers that the light depends on the suddenness of the break, and that, provided the apparatus is properly designed, the quicker the break, the brighter will the light be. The quickest break can be made by the interposing in a circuit the most perfect dielectric in the minimum space of time. A vacuum is one of the best dielectrics known, and the Author has invented a method for so interposing it in a circuit. This is done by making an ordinary contact-breaker with the contact-points in a vacuum. The disruption of any current in the air results in the formation of a spark of greater or less length, and the greater its length, the less sudden the break. Therefore if the break be made in a vacuum, the narrowest conceivable gap in the metallic conductor results in an almost instantaneous discontinuation of the circuit. This insures a maximum instantaneous electromotive force. The Author proceeds to describe the details of this contact-breaker in vacuum, and shows that a much higher vacuum is required in the contact-breaker tube than in the light-giving ones. The next point considered is the construction of the tube to be used for light-giving purposes. A great variety of them are illustrated, and described together with their lighting effects. The different possible connections of the apparatus and the tubes are shown. It is worthy of note that equal lighting effects are produced in the tubes when they are connected in parallel across with the spark gap on the magnet of the interrupter. When such tubes are connected in parallel, care must be taken that all the negative electrodes have the same area, otherwise the tube with the largest area alone will light up. The design of the magnet of the interrupter requires great care, as it has to fulfil two functions, *i.e.*, that of an inductive resistance and the actuating power for the contact-breaker. With too much iron the light suffers, and yet sufficient iron must be present to work the interrupter. A suitable small inductive resistance placed in parallel with each tube makes the system automatic, so that any tube can be switched off without varying the light of the others. The Author reserves his figures of cost and efficiency till he has experimented further, but a committee of experts after the lecture determined the following data.[1] The first measurements were taken with a Weston milliampere meter in the different circuits, and with a Weston voltimeter. The average current per tube was about 105 milliamperes, and the pressure 485 volts. This gives an expenditure of power of 51 watts per tube. This committee were not satisfied that these readings were reliable owing to the high frequency of the current.

[1] *The Electrical Engineer*, New York, vol. xxi., 1896, p. 558.

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They then proceeded to measure the power given to the motor supplying the main current. It was found that this required 985 watts more when the tubes were on than when they were off. There were in operation fourteen tubes, each 7½ feet long and 1¾ inch diameter; one tube somewhat shorter was 2½ inches diameter, and a few tubes of special design. It was estimated that the whole were equivalent to sixteen of the larger tubes. This gives 61·6 watts per tube at the motor terminals, and allowing 80 per cent. for the efficiency of the motor—49 watts per tube. This result confirms the direct readings. The committee state that it was not possible to obtain a reliable estimate of the candle-power given. Good photographs were, however, obtained of the room so lighted with an exposure of only one minute. The Paper is liberally illustrated.

R. W. W.

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## *A New Method of Studying the Light of Alternating Arc-Lamps.*

By Prof. W. L. PUFFER.

(Transactions of the American Institute of Electrical Engineers, 1896, p. 73.)

In order to show the great fluctuations in the light of an alternating-current arc, due to the intermittent heating of the carbon points, the Author has devised a stroboscopic method which gave excellent results. A hand-regulating arc-lamp was placed in a lantern with a large achromatic lens so adjusted as to make an image of the arc about 10 feet long on the screen. A transfer switch and suitable resistances were arranged for using either direct current or an alternating current of about 15 amperes for comparative purposes. At a convenient point a disk of about 18 inches diameter (in which were cut eight narrow radial slots) was placed so that the beam of light was interrupted as the disk revolved. The disk was fixed to the shaft of a direct-current motor whose speed was capable of adjustment by means of resistances in the armature circuit.

Such an apparatus shows very clearly the alternating arc as a series of direct-current arcs, alternating in polarity, each wave of current producing all the attributes of a direct-current arc.

By using a disk with half as many slots as there are pole-pieces on the dynamo, and driving it from the shaft of the machine itself, further interesting developments may be shown, and a series of photographs may be taken to illustrate the changes of light intensities during a single phase, ten or twelve exposures serving for the purpose. Amongst the more interesting investigations made by the Author may be cited the following:—With 500 volts, and a large non-inductive resistance in series with the arc, the current wave appears very nearly sinusoidal, the time of extinction of the arc being very short and the rise and fall of the

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current gradual and regular. The opposite conditions are seen when using a lower electromotive force and a reactive coil; an unsteady arc results, the time of no current is longer, and the maximum value reached in very small angular time. The succeeding waves of current are seen clearly to be dissimilar in form and value, and the angle of lag changes constantly.

Other experiments are described; some with three carbons and two circuits making the arc the common junction; also by driving the disk from a synchronous induction motor.

F. B. L.

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*The New Electrotechnical Institute of the Royal Technical High School in Hanover.* By W. KOHLRAUSCH.

(Elektrotechnische Zeitschrift, 1896, p. 341. 6 Figs.)

The Electrotechnical Institute of the Technical High School in Hanover was founded in the summer of 1884. Since then the whole school has been much enlarged, and on the 24th of October, 1895, the new part was opened by the Minister of Education.

The whole of the laboratories, machine-room, and drafting-room are on the ground-floor, and the height in the clear is between 11 feet 6 inches and 12 feet 6 inches. The first floor, which is 20 feet high in the clear, contains the lecture theatre and the preparation room, while the basement, 8 feet 6 inches in the clear, contains the motor-room and the workshops. All the rooms are heated by low-pressure steam and well ventilated. The lighting is effected by Wenham, Argand, and ordinary burners, but the theatre is lighted by eighty-four glow lamps. The flooring is of oak blocks in the drafting-room, lecture theatre, and a few other places; the engine-room has a terrazzo floor, the accumulator-room asphalt, and the rest is concrete with a cement screed covered with linoleum. No specially-built pillars are needed for mirror galvanometers and similar apparatus, as the floors are perfectly steady.

No rooms are free from iron; in the laboratories for heavy currents the D'Arsonval galvanometers can be used, and all the rooms are affected by the earth-currents from the street railway. Photographs of the interior are given in the original. The engine-room contains three gas-engines, one twin engine put down in 1884, the second a new single cylinder 12-HP. engine. The main shaft can be run at speeds varying from 160 to 400 revolutions per minute by means of a five-stepped pulley.

Between these two gas-engines is another of 12 HP. direct coupled to an eight-pole direct-current machine, giving 60 to 170 volts, with a maximum of 75 amperes. The speeds can be varied and a maximum of about 32 HP. obtained altogether.

Any dynamo can be driven by any engine. Each engine is

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fitted with a meter, a brake and indicator gear, and all the products of combustion are carried to a stack 49·2 feet high at a distance from the building.

The machine-room is over the engine-room, and the floor is of artificial stone on rolled steel joists; the dynamos are carried on joists bedded on blocks built in cement and anchored to the floor.

The machines consist of six direct-current dynamos of various types giving 1,000 to 5,000 watts, and capable of having their connections altered as desired; the largest will give single-phase, or two-phase, or rotary current. Transformers are also in use and other machines are to be added. A transmission dynamometer of the von Hefner Alteneck type is used.

The Author gives details of the various testing resistances and of the cable connections. Machines can if necessary be taken up into the lecture theatre for inspection.

There is a special laboratory for magnetic measurements, and in it a dynamo with the fields wound but without armature winding, and specially intended for experimental work.

In the drawing-office are also kept the various models used for teaching, such as a model of a central station switchboard, etc.

In the accumulator-room are three batteries, and the oldest cells have been in use eight years without any plates being replaced; there are a very large number of cells.

In the switchboard-room is the general switchboard with sixteen horizontal bars, and thirty pairs of vertical bars; this is so arranged that by means of the accumulators potentials varying from 10 volts to 200 volts can be easily obtained—the latter is obtained from a special battery of 100 cells. The whole of the current is therefore controlled from one place. The mains are carried on porcelain insulators, and pass through the walls in Bergmann tubes with porcelain ends. The Author gives full details as to the number of pegs on the distribution-boards in each room. Other rooms are used for photometry and minor purposes, and the workshops appear to be well supplied with machine tools.

There are seats for 236 students in the lecture theatre, and special arrangements are made for showing diagrams on a screen by means of a 20-ampere arc lamp and lantern.

About ninety beginners and sixty advanced students can work at once, but the latter do not work at the same hours as the former; the beginners work in pairs and the others in such groups as may be necessary. At present there are seventy-nine beginners and forty-six advanced students.

The Author in conclusion lays great stress upon the practical work which is done in the school.

E. R. D.

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## *Contributions to the Study of Fluorescence.* By G. C. Schmidt.

(Annalen der Physik und Chemie, vol. lviii., 1896, p. 103.)

Many substances which are not, under ordinary circumstances, fluorescent, become so when dissolved in a suitable medium, and others which show the phenomenon in the solid state cease to do so when melted or dissolved. The Author and E. Wiedemann have shown[1] that this may be explained upon the hypothesis that the vibrations which constitute fluorescence are damped by the influence of surrounding molecules. When light is absorbed by a coloured substance it may reasonably be supposed that a corresponding amount of energy is expended in causing molecular oscillations, and it may therefore be expected that any substance capable of absorbing light would be capable also, under suitable conditions, of fluorescing. The Author has made a long series of experiments in support of this opinion, using the phosphoroscope made by E. Wiedemann.[2] The coloured substances employed (aniline dyes) were in a state of "solid solution" in various organic mediums, such as gelatine, albumen, sugar, etc., and the result of the investigation confirmed the Author's view. The colour of the fluorescence due to the dissolved substance is in many cases independent of that emitted by the solvent when the latter is capable of fluorescing, but there were some notable exceptions to this rule. In the spectroscope it was found to give, for the most part, a continuous band of light.

With Congo red and with Hoffmann's violet the fluorescence was green when the phosphoroscope was turned slowly, changing to red when the speed was increased.

After a brief discussion of the reasons why a given body should fluoresce in certain solvents and not in others, the Author proceeds to an examination, theoretical and experimental, of Lommel's theory of fluorescence,[3] and arrives at the following general conclusions:—

(1) All substances are capable of fluorescing when embedded in a suitable solvent.

(2) Such substances in general only fluoresce when in a state of "solution."

(3) Lommel's theory is not confirmed by these experiments.

G. J. B.

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[1] Wiedemann's Annalen, vol. lvi. p. 203, 1895.

[2] *Ibid*, vol. xxxiv. p. 453, 1888.

[3] E. v. Lommel, Poggendorf's Annalen, vol. clix. p. 520, 1876, and Wiedemann's Annalen, vol. iii. p. 113, 1878.

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## *Turrets worked by Electrical Power.* By GÉRARD LAVERGNE.

(Le Génie Civil, July 4, 1896, p. 145.)

The use of electricity for motive power is now not unusual in ships of war, and the Author of this Paper describes what may be considered the typical Canet electrically-driven naval turret. The arrangements described are those for the 4·7-inch quick-firing gun, and for heavier guns of from 7·5-inch to 9·5-inch calibre.

After describing the general design of the gun-carriage itself, the Author proceeds to deal with the mechanism for moving the gun. The elevating and depressing, which does not require much power, is arranged to be done by hand, the range of this motion being between 15° above the horizontal plane to 6° below. The sights project through the top of the turret and are not mounted directly on the gun, while the aiming is done from a hood projecting above the top of the turret. The rotation of the turret is done by an electric motor coupled directly to a worm which gears into a worm wheel on a pinion which in turn drives the large-toothed wheel encircling and fixed to the shaft of the turret. The turret can also be turned by hand if necessary, one man being capable of rotating the turret for the 4·7-inch gun, while two men are required with heavier guns. The ammunition lift, which is in the form of an endless chain, is worked by hand for the smaller guns; but for the larger ones it is driven by a motor.

A special feature in the working of these turrets is the electrical controller, by means of which the training of the gun is controlled. This instrument is designed to control the movement of the turret as follows: rotation in either direction by a corresponding movement of the controlling lever with smoothness of motion however quickly the lever is moved; stoppage of rotation without shock however sudden; sensitiveness for slight movement to enable the gun to be sighted accurately; and automatic stoppage of the turret at the limits of angular training directly the stop-buffers are touched. The arrangement of this controller is not very easily grasped without the aid of a diagram. Keyed to the shaft of the lever are two revolving switches; two of the three contact pieces of the first are joined up, one to each of the circuit breakers on the stop-buffers at the limits of angular motion, while the six contacts of the other switch are arranged for reversing the motor. Thus motion of the lever in one direction will rotate the motor and turn the turret in the corresponding direction, while the circuit will be interrupted directly the stop-buffer is touched at the limit of motion in this direction. On the lever shaft is also keyed a toothed arc which rotates an electro-magnet. This magnet is excited whenever the lever is moved, so long as the stop-buffers are not touched; and while excited it attracts a shoe carrying a locking stud, which causes the arm of the starting switch of the motor to rotate with the magnet and move over the stops of the starting resistance, the extent of this motion varying with the

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amount of movement given to the lever. As soon as the current is interrupted, however, by the turret touching either one or other of the stop-buffers, the shoe is released and the starting switch springs back to its neutral position—in which the motor is also short-circuited—thus bringing the turret to rest almost instantaneously. This neutral position also corresponds to the neutral position of the controller lever, and to regain control after the current has been thus interrupted, it is necessary to return the lever to this position. The connections are so designed that while the electro-magnet revolves in either direction with the lever, the starting switch is always turned in the same direction. The whole apparatus, with the starting resistance, is enclosed in a metallic cylindrical case, placed so that the lever is close to the gunner's hand.

The Author concludes with a description of the ammunition lifts. For a 9·5-inch gun turret the ammunition lift is driven by an 8-HP. motor, while the training is easily done by a 15-HP. motor; and the training of a 4·7-inch gun turret is done by a 3-HP. motor. A 5·5-inch gun turret was revolved through 180° in thirty seconds, while that for a 7·5-inch gun was turned through 300° in fifty seconds.

The article is illustrated by a full-page plate of details and three reproduced photographs of guns and their mountings.

R. B. M.

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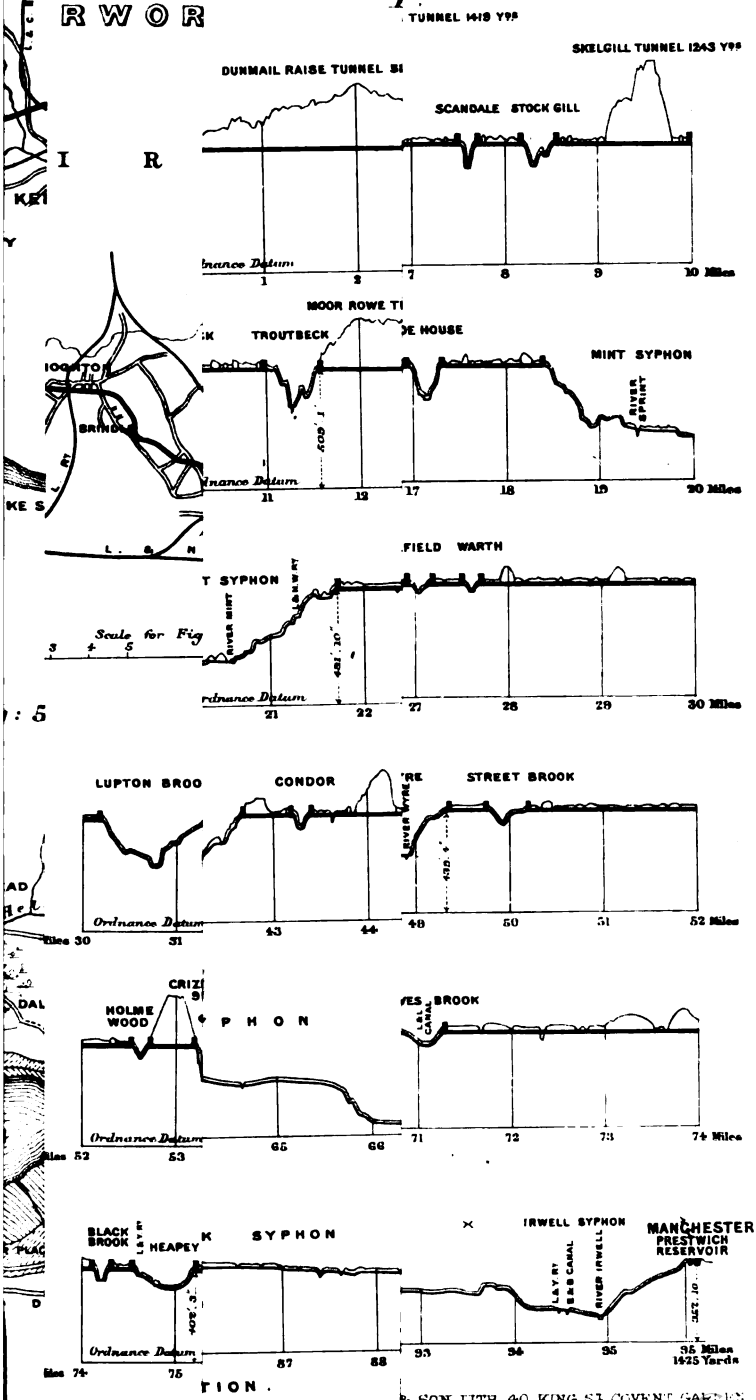


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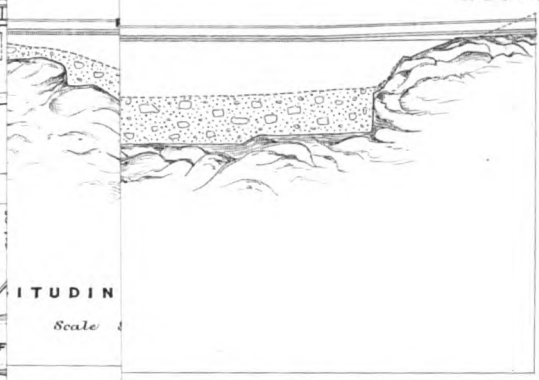


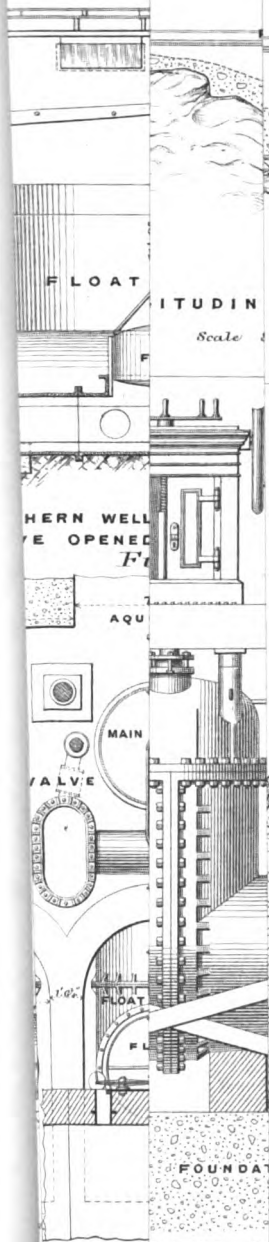
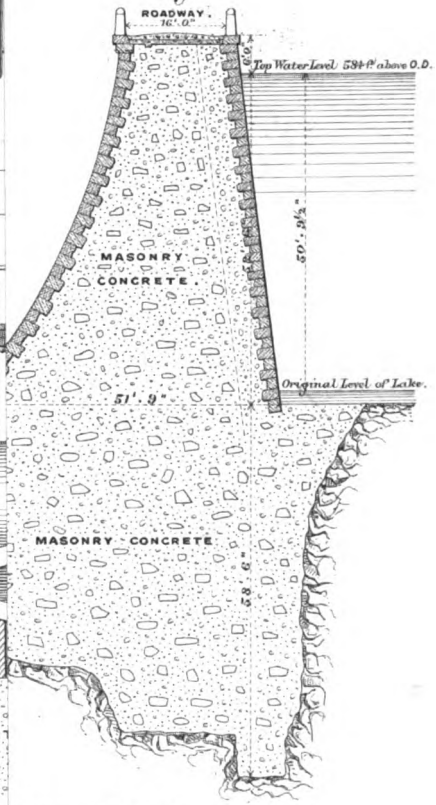



*Fig: 13.*




CROSS SECTION OF DAM.

Scale for Fig: 13.

for Fig: 14. 0 10 20 30 40 50 Feet.

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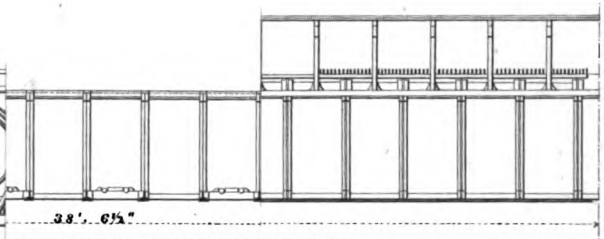


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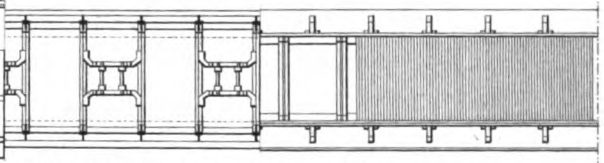
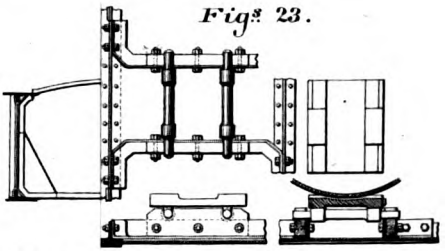


PART SECTIONAL PULL PLAN.

Figs. 23.



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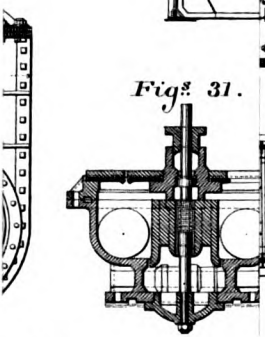

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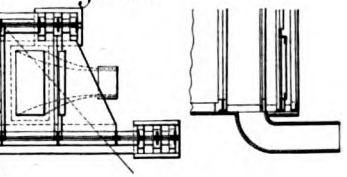
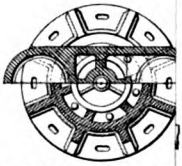
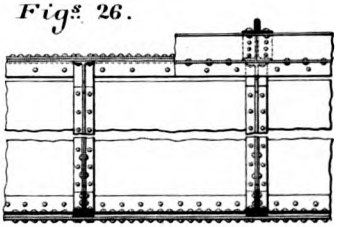


BACK.

Figs. 26.





Scale for Figs. 18 and

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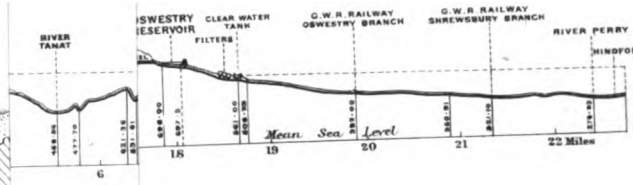
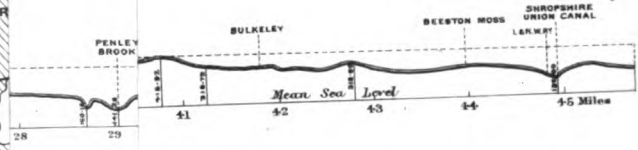
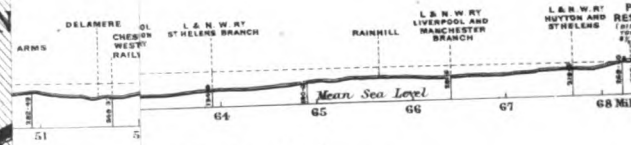
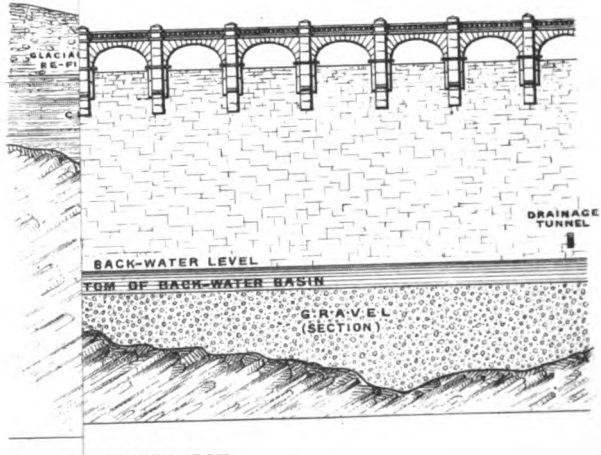



Figs 2 2 Miles 1,600 Feet to 1 Inch.
2 2000 3000 Feet




MASONRY DAM
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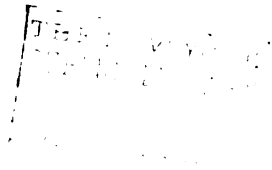

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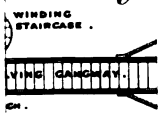
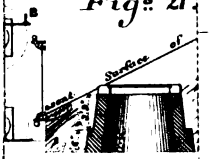



PLAN OF REVOL
NORTON

Figs. 21

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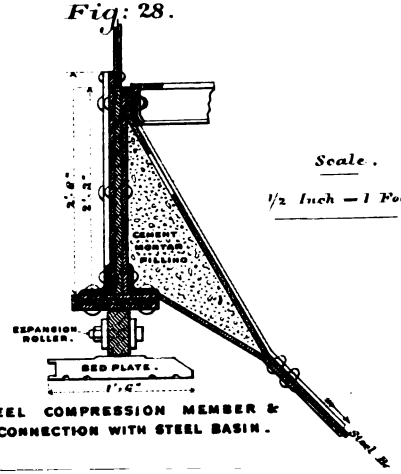


Scale.

1/2 Inch = 1 Foot.

STEEL COMPRESSION MEMBER & CONNECTION WITH STEEL BASIN.

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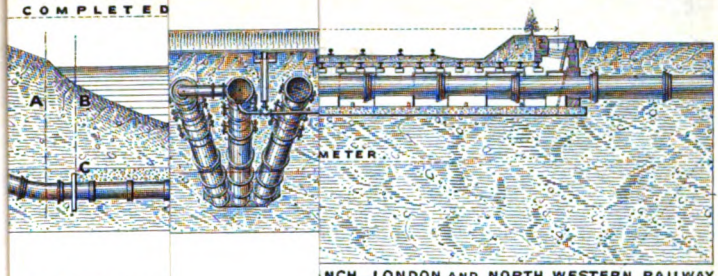
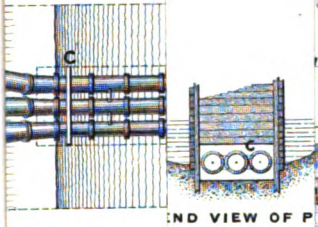



METER.

NCH—LONDON AND NORTH WESTERN RAILWAY.




igs 37.

VENTILATOR.

O.S.T. Level.

ND VIEW OF P
FROM COFFER-D

DATAM.

KT.

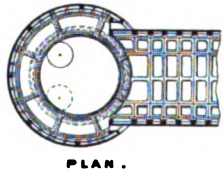
35 30 Feet to 1 Inch.
30 40

Feet to 1 Inch.

Feet to 1 Inch.
10

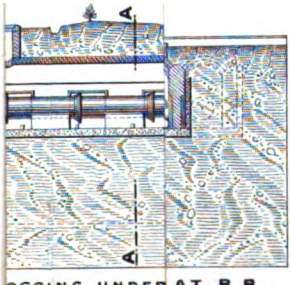
Feet to 1 Inch.
20

MANCH



PLAN.

EDUCT TUNNEL—CHESHIRE SHAFT.




Feet.

OSSING UNDER AT B B.



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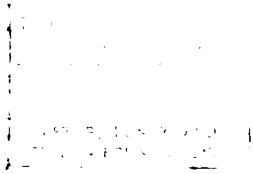

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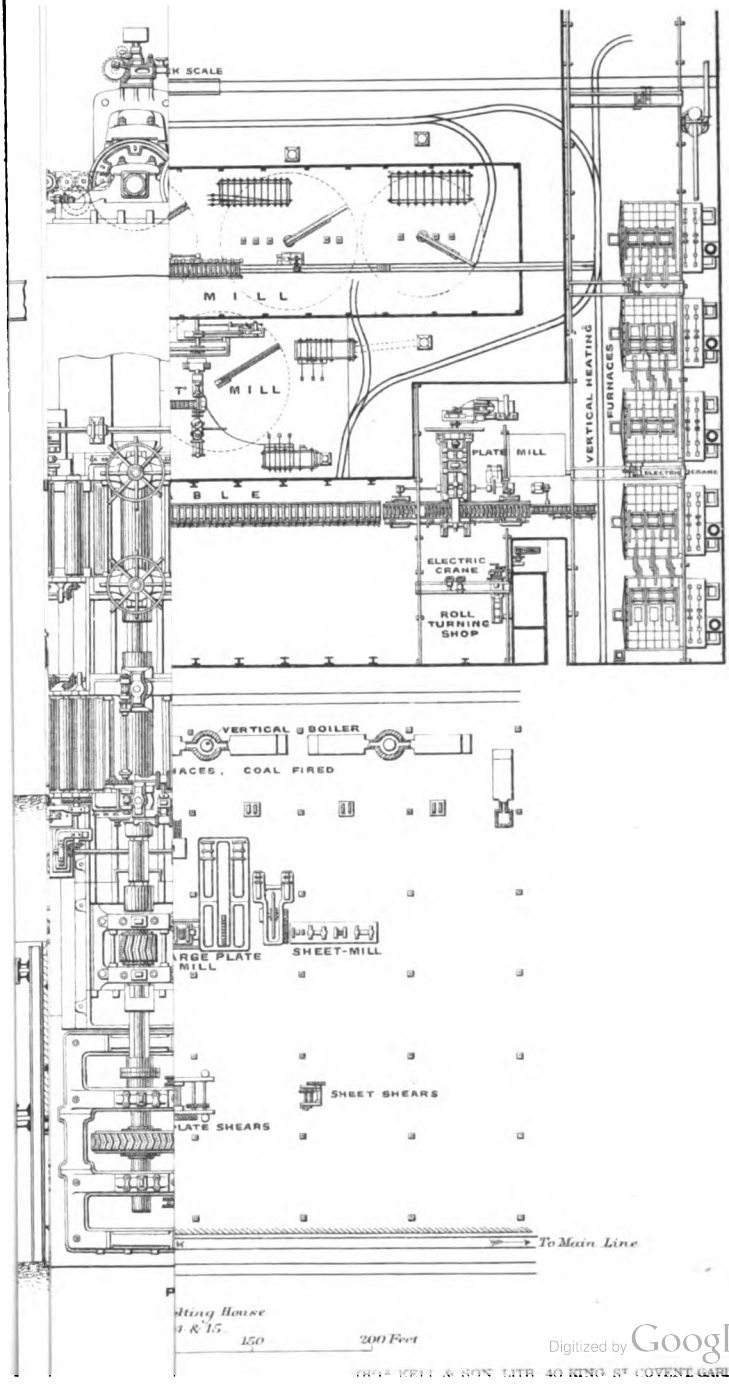


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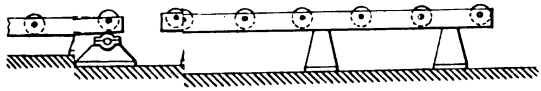
Figs 4

PLATE 8.



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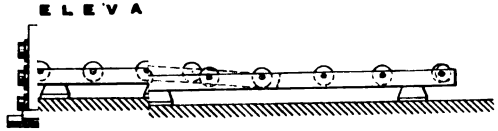

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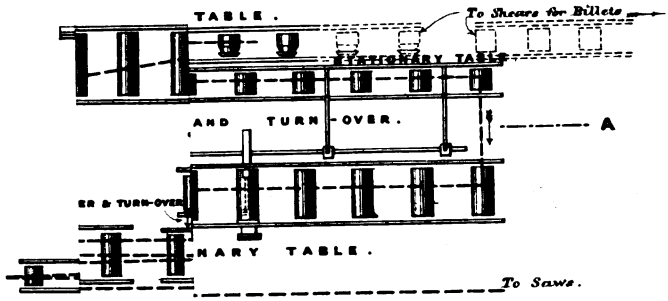


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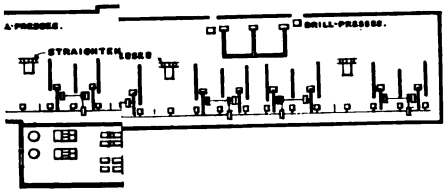


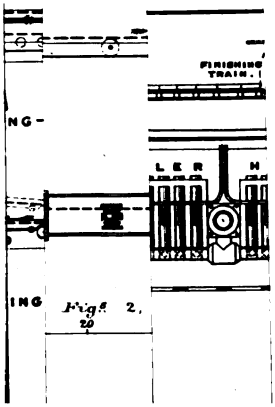


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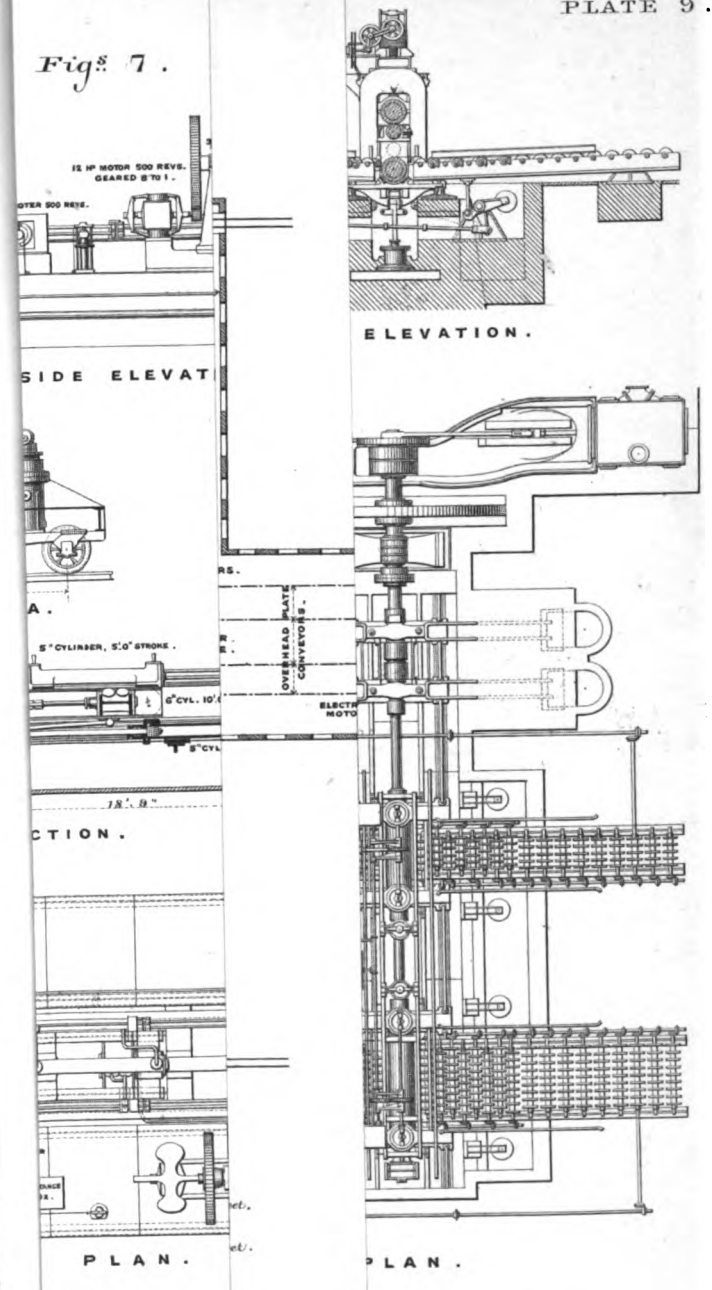
*Figs. 7.*

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